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Journal

of

THE ROYAL AERONAUTICAL SOCIETY

MARCH 1961

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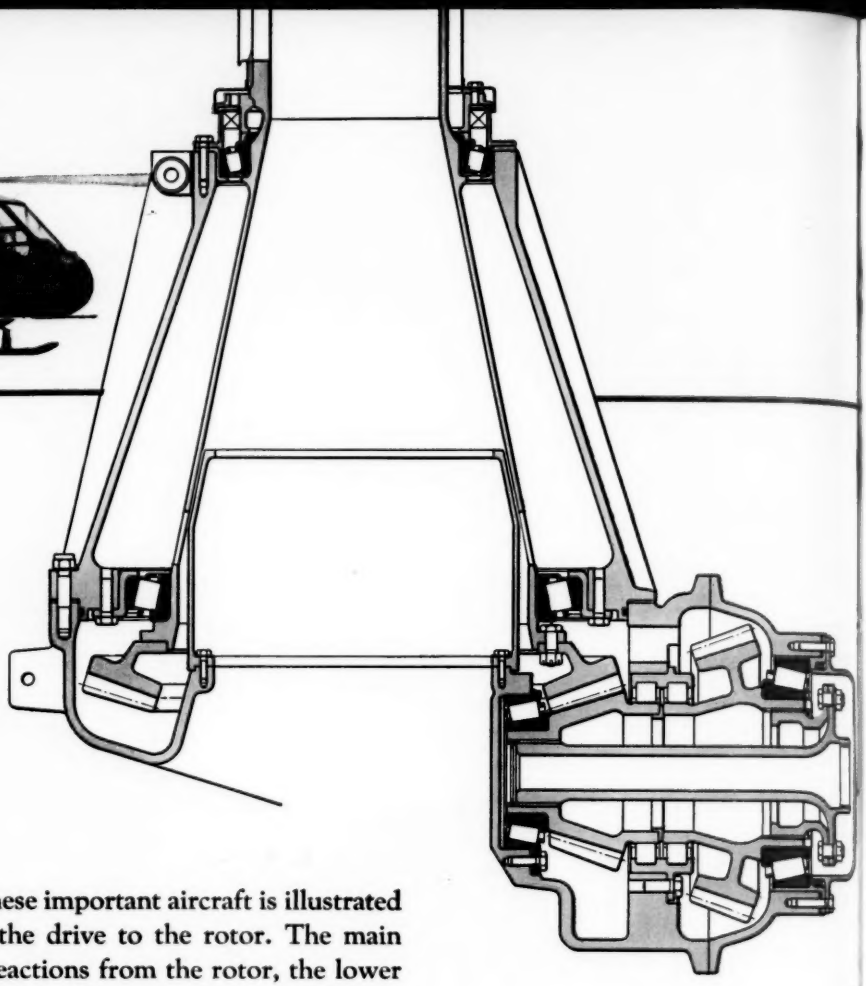

ON THE WESTLAND 'WASP' AND P531

THE secondary gearbox of these important aircraft is illustrated in the drawings, and takes the drive to the rotor. The main rotor bearings take all the reactions from the rotor, the lower bearing sustaining the whole weight of the aircraft when in flight.

An interesting feature is the construction of each intermediate shaft: the two bevels are coupled by a splined 'quill' with a flanged connection; this construction provides a fine vernier adjustment to time the bevels in load-sharing relationship, and in addition provides some torsional elasticity and accommodates any minute radial misalignment.

Fine axial adjustment of bevels and pre-load of the Timken bearings is effected by shims behind the flange of the small bearing and the end cover: there is also, between the bevel bosses, a selected washer which transmits the pre-load.

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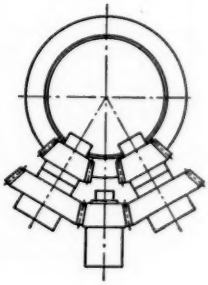
British Timken, Duston, Northampton, Division of The Timken Roller Bearing Company. Timken bearings manufactured in England, Australia, Brazil, Canada, France and U.S.A.



As is shown in the above diagram, a bevel gear on the input shaft meshes with a larger bevel on each of two intermediate shafts; these in turn have smaller bevel gears meshing with the crown wheel on the rotor shaft, giving an overall reduction. In this way the drive is taken off the input bevel at two places, and received by the crown wheel at two places.

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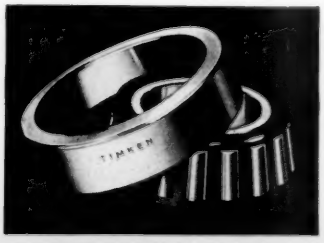

Journal of
THE ROYAL AERONAUTICAL SOCIETY
INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

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All communications for publication in the JOURNAL *should be addressed to the Editor,* JOAN BRADBROOKE, *A.R.Ae.S.; all communications on general matters affecting the Society should be addressed to the Secretary,* A. M. BALLANTYNE, *T.D., B.Sc., Ph.D., F.R.Ae.S., Hon.F.C.A.I., F.I.A.S.*

None of the papers or paragraphs must be taken as expressing the opinion of the Council of the Royal Aeronautical Society unless otherwise stated.

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(Founded 1866)

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NOTE: Under the revised By-Laws, allowed on 11th January 1960, the President of each Division and the Chairman of each Section of the Society is a Member of Council by reason of his office.

NOTICES

Annual General Meeting, 4th May 1961

NOTICE IS HEREBY GIVEN that the Annual General Meeting of the Royal Aeronautical Society, with which are incorporated the Institution of Aeronautical Engineers and the Helicopter Association of Great Britain, will be held on Thursday 4th May 1961, at 6.30 p.m., in the Offices of the Society, 4 Hamilton Place, London, W.1.

Agenda

1. To read the Notice convening the Meeting.
2. To receive and deliberate upon the Report of the Council on the state of the Society and the Balance Sheet and Income and Expenditure Accounts of the Royal Aeronautical Society and Aeronautical Trusts Limited for the year ended 31st December 1960.
3. To receive the names of those elected to Council for the years 1961-1964.
4. To elect the Auditors for the year 1961.
5. Any other business.

By Order of the Council,
A. M. Ballantyne,
Secretary.

NOTE: In accordance with the By-Laws any member whose subscription has not been paid before the first day of April is not entitled to vote.

Light refreshments will be served before the meeting.

Nomination of Candidates for Council

The following is an extract from the amended By-Laws.

(A) *Composition of Council*

The Council shall consist of the President, the three most recently retired Past-Presidents who are willing and able to serve, the President-Elect, the President of each Division, and twenty-one ordinary members of Council. In addition the Chairman of each Section shall be a member of Council by reason of his office, if he is not already a member of Council.

(C) *Ordinary Members of the Council*

The twenty-one ordinary members of the Council shall be nominated and elected among the members of the Society. At the date of their election at least ten shall be Fellows, and one each at least shall be an Associate Fellow and an Associate. At least one other shall be a Graduate, unless a Graduate is already *ex-officio* member of Council as Chairman of a Graduates' and Students' Section of the Society.

Of the ordinary members of the Council that number necessary to create seven vacancies shall retire at each Annual General Meeting. Subject to the provisions of this By-Law as to regraded members the retiring members shall be those with the longest service since their last election. A retiring member shall be eligible for re-election.

Nominations of candidates for election to the Council must be received by the Secretary not later than **the tenth day of April** in each year and shall include statements in writing by the candidates that they are willing to serve. The nomination form shall be signed by one proposer and two seconders, all of whom shall be Voters.

Nomination forms may be obtained from the Secretary.

The Fourteenth Louis Blériot Lecture

The Fourteenth Louis Blériot Lecture, Problems of Short Take-off and Landing, by General H. Ziegler, General Manager, S. A. Louis Breguet, will be given on Thursday 23rd March 1961, in the Lecture Theatre, 4 Hamilton Place, W.1, at 6 p.m. (tea at 5.30 p.m.).

Easter Holidays

The Offices and Library of the Society will be closed from Thursday afternoon 30th March until Tuesday 4th April.

Symposium on the Training of Guided Missiles Engineers

An All-Day Symposium on the Training of Guided Missiles Engineers will be held on 16th March 1961 in the Lecture Theatre, 4 Hamilton Place, London W.1, beginning at **10.30 a.m.** *Please note change of time.*

The Symposium will be opened by the Chairman, Mr. A. V. Cleaver, of Rolls-Royce Ltd. Speakers taking part will be:—Mr. L. H. Bedford, The English Electric Co. Ltd., Dr. G. H. Hough, de Havilland Propellers Ltd., Mr. A. M. Christmas, Director of Techniques, Guided Weapons Dept., R.A.E., Farnborough, Professor G. A. Whitfield, Professor of Aircraft Electrical Engineering, College of Aeronautics, Cdr. E. G. Allen, R.N., Professor of Naval Engineering, Royal Naval College, Professor C. Holt Smith, Royal Military College of Science, Wing Cdr. G. C. Wainwright, Chief Instructor Weapon Systems, Engineering Wing, R.A.F. Technical College, Henlow. The Discussion will be opened by Mr. M. Armstrong, Chief Training Engineer, Bristol Aircraft Ltd., and University and Army representatives.

Admission will be by ticket only. Tickets may be obtained from The Secretary, Royal Aeronautical Society.

Symposium on Air Traffic Control

An All-Day Symposium on Air Traffic Control will be held on Thursday 20th April in the Lecture Theatre, 4 Hamilton Place, London, W.1, beginning at 9.30 a.m.

Air Vice-Marshal Sir Laurence Sinclair, Controller of Aviation Ground Services, will take the Chair. Speakers taking part will be: Group Capt. J. B. Veal, Director-General of Navigational Services; Arnold Field, Master of the Guild of Air Traffic Control Officers; A. E. Slocombe, Superintendent of Aerodromes and Air Traffic Control, B.E.A.; Air Cdre. J. B. Russell, Director of Operations Maritime, Navigation and Air Traffic Control; E. W. Pike, General Precision Systems Ltd.; a representative of Telecommunications and Air Traffic Control Dept., Dept. of Civil Aviation, Holland; J. Anast and Albert Brown, Bureau of Research and Development, Federal Aviation Agency; K. E. Harris, Director and General Manager, Cossor Radar and Electronics Ltd.; G. H. Throw and Capt. V. A. M. Hunt, Director, Control and Navigation Development and Planning, Ministry of Aviation; R. F. Hansford, Decca Radar Ltd.; J. F. Holford, R.A.E., Farnborough, and D. Lean, R.A.E., Bedford.

Admission will be by ticket only—obtainable from the Secretary, Royal Aeronautical Society, 4 Hamilton Place.

Historical Group Discussion Evening

The Historical Group will hold a Discussion Evening on Monday 10th April in the Lecture Theatre. The subject will be "A Quiz on Little Known Early Aircraft." The Aircraft Recognition Society has been invited to join members of the Group in examining slides of aircraft, the identities of which have been forgotten or are known only to connoisseurs. A panel of experts will aid the discussion.

Eighth Anglo-American Aeronautical Conference

The Eighth Anglo-American Aeronautical Conference will be held at 4 Hamilton Place, London, W.1 from 3rd to 14th September 1961. Details will be published later.

S.E.E. Annual General Meeting

The Annual General Meeting of the Society of Environmental Engineers will be held at the Royal Society of Arts, John Adam Street, London, W.C.2 at 2.30 p.m. on 24th March.

DIARY

MAIN SOCIETY

All lectures in London will be held in the Lecture Theatre, 4 Hamilton Place, unless otherwise stated.

17th March
MAN POWERED AIRCRAFT GROUP—Power Transmission Systems. S. S. Wilson. **7 p.m.**

21st March
Some Aspects of Buffeting. R. Fail. **7 p.m.**

23rd March
FOURTEENTH LOUIS BLÉRIOT LECTURE—Problems of Short Take-off and Landing. General H. Ziegler. **6 p.m. (Tea 5.30 p.m.)**

29th March
AGRICULTURAL AVIATION GROUP—Atomisation. R. P. Fraser. **7 p.m.**

10th April
HISTORICAL GROUP—Discussion Evening. **7 p.m.** *See special notice.*

11th April
Direct Electrical Power Generation by Thermal and Chemical Means. Professor M. W. Thring. **7 p.m.**

19th April
AGRICULTURAL AVIATION GROUP—A Review of Current Developments in Agricultural Aviation. Dr. W. E. Ripper. **7 p.m.**

20th April
All-Day Symposium—Air Traffic Control. **9.30 a.m.** *See special notice.*

25th April
On the Origin, Structure and Growth of Vortex Separations. E. C. Maskell. **7 p.m.**

ASTRONAUTICS AND GUIDED FLIGHT SECTION

16th March
All-Day Symposium—The Training of Guided Missiles Engineers. **10.30 a.m.** *See special notice.*

GRADUATES' AND STUDENTS' SECTION

12th April
Man Powered Flight—Progress to Date. B. S. Shenstone. **7.30 p.m.**

ROTORCRAFT SECTION

2nd June **(Postponed from 7th April)**
Development of Stabilising Equipment for Helicopters. P. D. MacMahon. **6 p.m.**

BRANCHES

14th March
Luton—Hovercraft. Lecturer from Hovercraft Development Ltd. Napier Senior Staff Canteen, Luton Airport. 6 p.m.

15th March
Coventry—Reliability. Air Vice Marshal A. F. Hulton. Herbert Art Gallery. 7.30 p.m.
Manchester—Sixth Chadwick Memorial Lecture—Some Current Problems Facing the Aircraft Designer. J. C. Floyd. Reynolds Hall, College of Technology. 7.30 p.m.
Reading—Development of the Handley Page Herald and H.P. (R) 8. J. Allan, F. Farrington and R. Davies. Lecture Theatre, Reading Technical College. 7.30 p.m.

22nd March
Preston—Some Requirements of the Modern High-Speed Motor Car. Frank Costin. R.A.F.A. Hall, Preston. 7.30 p.m.
Weybridge—She's All Yours—Experiences with the Introduction of the Viscount and Vanguard. Capt. R. Rymer. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd. 6 p.m.

28th March
Luton—Annual General Meeting and Presidential Address. F. H. Pollicutt. Napier Senior Staff Canteen, Luton Airport. 6 p.m.

29th March
Brough—The New "Bluebird." K. W. Norris and L. F. Norris. Royal Station Hotel, Hull. 7.30 p.m.
Christchurch—Lecture by G. Wakefield. King's Arms Hotel. 7.30 p.m.
Reading—Annual General Meeting and Film Show. Hawkhurst Canteen, Western Manufacturing Ltd. 6 p.m.
Southampton—Annual General Meeting. Engineering Lecture Theatre, University of Southampton. 8 p.m.

5th April
Southend—Annual General Meeting and Film Show. Room 3, Engineering Department, Municipal College, London Road. 7.30 p.m.
Swindon—An Introduction to Aircraft Materials. A. Black. The College, Victoria Road, Swindon. 7.30 p.m.

6th April
Glasgow—Graduates' and Students' Section—Annual General Meeting and Lecturettes by members of the Section. Scottish Aviation Ltd., Prestwick Airport. 7.30 p.m.
Isle of Wight—Modern Trends in Passenger Ship Design. J. West. Saunders-Roe Clubhouse, Church Path, E. Cowes. 6 p.m.

10th April
Boscome Down—Film Show. Lecture Hall, A. & A.E.E., Boscombe Down. 5.30 p.m.
Derby—Joint Lecture with the Derby Centre of the Automobile Division of the Institute of Mechanical Engineers—Progress in the Lubrication of Gas Turbine Engines. J. S. Elliott. Rolls-Royce Welfare Hall, Nightingale Road. 6.15 p.m.

11th April
Gloucester and Cheltenham—Annual General Meeting and Film Show. Wheatstone Hall, Brunswick Road, Gloucester. 7.30 p.m.
Luton—Reliability. Air Marshal Sir Herbert Spreckley. Napier Senior Staff Canteen, Luton Airport. 6 p.m.

12th April
Hatfield—Discussion Evening. de Havilland Restaurant. 6.15 p.m.
Preston—Experimental Stress Analysis. Dr. B. Parsons. Group Leaders' Canteen, English Electric Aviation Ltd., Warton. 5.30 p.m.

13th April
Belfast—Annual General Meeting.

19th April
Christchurch—Annual General Meeting and Film Show. King's Arms Hotel. 7.30 p.m.
Coventry—Annual General Meeting and Film Show. Herbert Art Gallery. 7.30 p.m.
Weybridge—Annual General Meeting. Apprentice Training School, Vickers-Armstrongs (Aircraft) Ltd. 6 p.m.

20th April
Derby—Hovercraft. C. S. Cockerell. Hucknall. 5.45 p.m.
London Airport—Annual General Meeting and Lecture—Space Travel. A. V. Cleaver. Senior Mess, B.O.A.C. H.Q., London Airport. 6 p.m.

21st April
Hatfield—Annual Dinner. de Havilland Restaurant. 6.15 p.m.

26th April
Hatfield—The Halford Memorial Lecture. Dr. S. G. Hooker. Main Hall, Hatfield Technical College. 6.15 p.m.

JOINT MEETING WITH THE INSTITUTION OF ELECTRICAL ENGINEERS

A Joint Meeting with the Institution will be held at the Institution of Electrical Engineers, Savoy Place, London, W.C.2 on Tuesday 18th April. A lecture on "Electronics in Aircraft and Guided Missiles" will be given by the Rt. Hon. Viscount Caldecote.

CONFERENCE ON THE MECHANICS OF RUPTURE

A Conference on the Mechanics of Rupture, organised by the Stress Analysis Group of the Institute of Physics and the Physical Society, will be held at Southampton University from 24th to 27th April 1961.

Full details and Conference programmes may be obtained from L. Lawrence, Esq., Administrative Assistant, The Institute of Physics and the Physical Society, 47 Belgrave Square, London, S.W.1.

HELICOPTER ASSOCIATION OF GREAT BRITAIN

An Extraordinary General Meeting to present the Final Accounts of the Helicopter Association of Great Britain was held on Friday 13th January.

Mr. F. R. Reber, the Liquidator, presented the final accounts showing the winding up of the Association and the manner in which the disposal of the property of the Association had been effected.

Election of Fellows

The following have been elected to Fellowship:—

Rupert Beaney, Service Manager, Aircraft Service Dept., Short Bros. and Harland Ltd., Belfast.

John Crowe Bissett, Chief Test Engineer, Short Bros. and Harland Ltd., Belfast.

Thomas William Brooke-Smith, formerly Chief Test Pilot, Short Bros. and Harland Ltd., Belfast.

Michael Golovine, Managing Director, A.T.S. Co. Ltd., Hawker Siddeley Group Ltd.

Richard Greinacher, Aeronautical Supervisor, Swiss Military Aircraft Evaluation Team.

William Littlewood, Vice-President, Equipment Research, American Airlines Inc.

John Lockwood Taylor, Professor of Aeronautics, Technical University of Norway (N.T.H.).

Douglas Ian Vickery, Assistant Chief Engineer, Bristol Aeroplane Co. Ltd., Filton.

Charles Hugh Elsey Warren, S.P.S.O., Head of General Supersonics, Aero Dept., R.A.E.

Rotorcraft Section

At the First Annual General Meeting of the Rotorcraft Section held on 13th January the results of the ballot were announced. The Section Committee for 1961 is as follows:—

Professor J. A. J. Bennett
Wing Cdr. R. A. C. Brie
Capt. J. A. Cameron
O. L. L. Fitzwilliams
L. G. Frise
R. Hafner
N. J. G. Hill
Dr. G. S. Hislop
C. T. D. Hosegood
A. McClements
Lt. Col. J. W. Richardson
Dr. H. Roberts
W. H. Sear
J. S. Shapiro
R. H. Whitby
J. D. Brown (*Graduates' and Students' Section Representative*)

Whitworth Foundation Awards, 1962

Applications are invited for three Fellowships and three Exhibitions to be offered in 1962 on the Foundation of Sir Joseph Whitworth.

Full details of the awards (Form 50 F.E.) and Application Forms (Form 51 F.E.) may be obtained from the Ministry of Education, Curzon Street, London, W.1.

Symposium on the Applications of Analogue Computers

A Symposium on the Applications of Analogue Computers will be held at The Loughborough College of Technology from 10th to 11th April 1961. Application forms and full details may be obtained from Dr. H. Buckingham, Dept. of Electrical Engineering, College of Technology, Loughborough, Leicestershire.

Institute of Welding

The 1961 Spring Meeting of the Institute of Welding will be held in London from 25th to 28th April. The theme of the meeting will be Recent Developments in the Welding and Allied Processes.

The Fourth Annual Lecture of the Institute will be given on 24th or 25th April at 7.30 p.m. by Dr. N. P. Inglis on Welding in the Non-Ferrous Field. Tickets may be obtained from the Institute of Welding, 54 Princes Gate, Exhibition Road, London, S.W.7.

Addition to New Year Honours List 1961

Group Captain A. W. Caswell (*Associate Fellow*) was awarded the C.B.E. in the New Year Honours List. (Unfortunately omitted from the previous list.)

Modern Greek Translation

The Library has received a paper on Missiles and Rockets written in Modern Greek. If any member would care to use this as an exercise in translation the Librarian would be pleased to hear from him.

Lecture Theatre Appeal

Donations continue to be received and the Fund will remain open for several more months. The final cost cannot be ascertained until certain modifications have been completed, but it is hoped that it will be possible to meet any additional expenditure out of the Appeal Fund.

In the meantime the following contributions received since the publication of the previous list are gratefully acknowledged:—

Donations	£	s.	d.
M. W. Anderson, Esq.	6	0	0
A. P. H. Bamford, Esq.	1	0	0
Sqn. Ldr. E. N. Beswick	4	0	0
F. N. Birkett, Esq.	3	0	0
A. C. Boswell, Esq.	3	0	0
E. F. Brereton, Esq.	1	0	0
A. W. Fia, Esq.	1	0	0
E. J. Gabbay, Esq.	3	3	0
C. Gibson, Esq.	1	0	0
A. G. Lowe, Esq.		10	6
M. R. Martin, Esq.	2	0	0
J. Pryor, Esq.	1	0	0
J. H. M. Smith, Esq.	3	3	0
Dr. P. A. Vasavada	1	0	0
J. V. A. Welbourn, Esq.	2	2	0
W. Wong, Esq.	1	1	0
7-Year Covenants			
Westland Aircraft Ltd.	263	17	6

(*with Income Tax at the present rate of 7s. 9d. in the £ this should produce £3,015 over the 7-year period*).

The Grand Total has now reached **£111,785 0s. 0d.** (approx.).

Elections

The following is a list of elections and transfers of membership of the Society:—

Associate Fellows

Edgar Bendor (*from Graduate*)
Jose Manuel de Sendagorta (*from Graduate*)
Colin Dicker
Gordon Maxwell Hensel
Raymond Paul Rose
Anthony Compton Southgate (*from Graduate*)

Associates

Victor Ambrose de Verteuil
Frederick Jan Jacobs
John Frederick Whittaker

Graduates

Stephen Richard Akhurst (*from Student*)
James Roger Craig
Allen Geoffrey Downhill
Kenneth John Holden (*from Student*)
Perincheri Kunhiraman (*from Student*)
Robert William Haviland Minchin (*from Student*)
Anthony Roger Chennel Tatham (*from Student*)
John Yeeles (*from Student*)

Students

Anthony John Berry
Terrence William Brown
William Macdonald Collins
Jai Krishan Dass Garg
Ian Howells
Michael Noel John Knott
John Roger Piercy
Richard Randell
Leonard Savage

Acknowledgment

The Council wishes to thank Mrs. A. C. Williams, of "Redroofs," Broadstone, for presenting to the Society two albums of photographs compiled by her brother, Wilfred Parke, one of the earliest test pilots who was killed in 1912. The Council is grateful also to Miss Constance Babington Smith who suggested to Mrs. Williams that the Society would be honoured to receive the albums. Parke's remarkable story is told in Miss Babington Smith's recent book *Testing Time*.

News of Members

D. G. Bader (*Student*) formerly Engineering Apprentice, de Havilland Aircraft Ltd., is now a Technical Engineer, Systems Group, Aircraft Engineering Department, Bristol Aircraft Ltd.

G. E. Beck (*Associate Fellow*) formerly Group Leader of Airborne Navigational Aid Development, is now Chief Engineer, Aeronautical Development, Marconi's Wireless Telegraph Co. Ltd., Basildon.

F. S. Bhinder (*Associate*) formerly Technician, Self Priming and Engineering Co. Ltd., is now Assistant Lecturer, Southall Technical College, Middlesex.

Capt. E. M. Brown (*Associate Fellow*) formerly Head of British Naval Air Mission, Germany, has been appointed Deputy Director (Air) Gunnery Division, Admiralty.

Sqn. Ldr. H. W. Chiverton (*Associate*) formerly at H.Q. Bomber Command, is now Officer in Charge, Airfield Training Squadron, R.A.F. Halton.

P. B. Clay (*Associate Fellow*) formerly with Rolls-Royce Ltd., Derby, is now a Project Engineer, Rolls-Royce of Canada Ltd., Montreal.

P. J. Daglish (*Associate Fellow*) Special Executive, D. Napier and Son Ltd., has been appointed Commercial Director.

F. R. E. Flower (*Associate*) formerly Assistant R.T.O. (A), Westland Aircraft Ltd., is now Assistant R.T.O.(A.), Bristol Aircraft Ltd.

R. H. Glynn (*Student*) formerly holding a Commission in R.E.M.E., has returned to Rolls-Royce Ltd., as a Designer in the Military Design Office.

Wing Cdr. G. R. Hadfield (*Associate Fellow*) formerly at Headquarters, Fighter Command, has been appointed O.C. Weapons Wing, Central Servicing Development Establishment.

H. T. Hill (*Associate Fellow*) of Wellworthy Ltd., Hampshire, has been appointed Managing Director.

Sqn. Ldr. J. N. Hullah (*Associate Fellow*) formerly Senior Engineering Officer, Air Electronics School, R.A.F. Hullavington, is now Senior Planning and Production Officer, No. 32 Maintenance Unit, St. Athan.

E. C. Jackson (*Associate*) formerly with the de Havilland Engine Co. Ltd., is now Chief Inspector A.I.D., Henry Shepherd Ltd., Cricklewood.

R. F. Jones (*Associate*) formerly serving as an Exchange Officer with the U.S.A.F. at Wright-Patterson Air Force Base, Dayton, is now serving at H.Q. 41 Group, R.A.F. Andover.

E. G. D. Lancaster (*Associate*) formerly Engineering Inspector, Malayan Airways, Kallang, A.P., is now Engineer in Charge of Aircraft and Component Overhaul, Gulf Aviation Company Ltd., Bahrain.

P. M. Lavelle (*Associate Fellow*) formerly with the Research Reactors Division at A.E.R.E., Harwell, has now transferred to the Directorate.

R. E. Leete (*Associate Fellow*) formerly Contracts Manager, Sperry Gyroscope Co. Ltd., is now Contracts Manager, Smiths Aircraft Instruments Ltd.

Sqn. Ldr. D. McK. McWilliam (*Associate Fellow*) formerly Transport Command, Work Study Team Leader, R.A.F. Upavon, has been appointed O.C. Air Engineering Squadron, R.A.F. Akrotiri, Cyprus.

Sqn. Ldr. A. M. C. Markey (*Associate*) on completion of a Staff College Course at Bracknell, is now on Technical Co-ordination duties at Headquarters, Coastal Command.

R. Meddick (*Graduate*) formerly Stressman, Blackburn Aircraft Ltd., is now a Stress Engineer, Vickers-Armstrongs (Aircraft) Ltd., Hurn Airport.

A. D. Munro (*Associate*) formerly Sales Engineer, has been appointed Deputy Sales Manager, Overseas Section, The Permutit Co. Ltd., London.

Sqn. Ldr. H. W. Newman (*Associate Fellow*) formerly Officer Commanding Ground Engineering Squadron, R.A.F. Marham, Norfolk, is now Senior Technical Officer, R.A.F. Woodhall Spa.

K. H. M. Noble (*Graduate*) formerly a Mathematician with Fairey Engineering Ltd., is now a Mathematician, Advanced Projects Group, Hawker Siddeley Aviation Ltd.

Sqn. Ldr. R. F. Plucknett (*Associate Fellow*) formerly at the Air Ministry, is now at H.Q., B.F.A.P., on Technical Co-ordination duties.

D. C. Roberts (*Graduate*) having completed a post-graduate Course in Nuclear Engineering at Queen Mary College, is now an Assistant Shift Charge Engineer, Atomic Energy Division, General Electric Co. Ltd., Ayrshire.

R. W. Roberts (*Graduate*) formerly at The College of Aeronautics, Cranfield, is now Research and Development Engineer, C. A. Parsons and Co. Ltd., Newcastle-on-Tyne.

G. E. Salt (*Graduate*) formerly Project Design Engineer, H. M. Hobson Ltd., Wolverhampton, is now Chief Designer, Mining Division, George Fletcher and Co. Ltd., Derby.

K. L. Sapsed (*Associate*) formerly Ground Services Engineer, Aviation Branch, B.P. Co. Ltd., is now with B.P. (Eastern Agencies) Ltd., at Bahrain.

G. M. Silvester (*Associate Fellow*) formerly Design Engineer, Boeing Airplane Co. Transport Division, is now Engineer, Re-Entry Vehicle Division, General Electric Co., Missiles and Space Vehicle Department.

Flt. Lt. D. J. Sledge (*Graduate*) formerly R.A.F. Technical Branch, B.F.P.O. 43, is now R.A.F. attached to A.W.R.E. Aldermaston.

C. Spear (*Associate*) formerly Aero Overhaul Engineer, D. Napier and Son Ltd., Acton, is now Quality Control Engineer, Inertial Navigation Division, Elliott Bros. (London) Ltd., Borehamwood.

I. H. Steels (*Graduate*) formerly Branch Manager, The Airscrew Co. and Jicwood Ltd., Newcastle, is now Technical Sales Manager, John Dalglish and Sons Ltd., Glasgow.

R. P. Taylor (*Graduate*) formerly Research and Development Officer, Design Department, Hawker Aircraft Ltd., is now a Flight Test Engineer, Short Bros. and Harland Ltd., Belfast.

P. J. Treweek (*Graduate*) formerly Post Graduate Apprentice, Hawker Aircraft Ltd., is now Assistant Lecturer, Wandsworth Technical College.

A. C. F. Visman (*Graduate*) formerly with the Royal Netherlands Navy, is now a Student in the Technical Physics Department for a five year course at the Technische Hogeschool, Delft.

S. H. Whitworth (*Associate*) formerly of Royal Netherlands Aircraft Factories, has been seconded to Pakistan International Airlines, East Pakistan, as Training Advisor.

G. L. Wilde (*Associate Fellow*) Project Engineer, Advanced Projects Aero Division, Rolls-Royce Ltd., Derby and formerly Chief of Compressor Aerodynamic Design and Development, has been appointed Chief of Preliminary Design. (Correction from January Journal).

Lecture Summaries

Historical Group

THE EVOLUTION OF TRANSPORT AIRCRAFT
PETER W. BROOKS

To be given on 13th March

The first air liners were direct developments, at the end of the First World War, of some of the more successful military aircraft of that time. Since then, there have been three main phases in the development of the airline industry and of transport aircraft:—

1919-39. The pioneering era. By the end of this period, the industry was within sight of profitable operation and transport aircraft had crystallised in the form of all-metal stressed-skin low-wing monoplanes with radial petrol engines.

1939-45. Truly commercial services were temporarily suspended over the greater part of the World during the War but a remarkable expansion of long-haul air transport took place using larger, longer range developments of the air liners of the immediate pre-War period.

1945-59. A period of continued rapid expansion but of operational and economic consolidation. Further developments of the earlier piston-engined equipment provided the bulk of the airlines' capacity but turbo-prop aircraft supplemented this in the latter part of the period and the first pure-jet entered service.

The aim of the lecture is to set into perspective the successive—and, it would seem, almost inevitable—steps by which the modern jet air liner has evolved from the first tentative transport aeroplanes, primarily under the direct stimulus of large-scale expenditure by Governments on military aviation.

Man Powered Aircraft Group

POWER TRANSMISSION SYSTEMS

S. S. WILSON

To be given on 17th March

Various elements of power transmission systems are examined under the headings:—(*i*) Efficiency, (*ii*) Weight, (*iii*) Stresses imposed on the structure by the drive, (*iv*) Effect on the drive of structural deflections, (*v*) Effect of cyclic variation of torque due to pedalling and to the propeller passing through the wake of a fin or pylon.

In view of the low speed and heavy peak torque, which lie outside the region of most power transmissions, and to distinguish marginal differences in efficiency between various drive elements, a transmission efficiency rig has been designed, capable of testing almost all possible types of drive.

The principle of power recirculation is employed so that only the lost torque is supplied, and this can be measured accurately, using an air-lubricated bearing. For positive drives a known torque may be locked into the system, while for belt drives in which there is a certain percentage difference in speed between input and output shafts due to slip and creep, a known percentage speed ratio is provided by the use of pulleys of slightly differing diameter and the torque when running adjusts itself accordingly. Results so far obtained are described.

Among the drives considered are chain and sprocket, toothed, flat, and vee belts, spur, and bevel gears, universal joints, the double crank and pushrod drive (twisted) and the use of a long thin shaft used in a circular arc.

The last proposal (which may be suitable both for the designs with the propeller at the tail and for those with a pusher propeller mounted on a pylon above the wing, with the pilot lying backwards and pedalling with his feet raised), envisages designing the system so that the shaft runs below its primary whirling speed but so that natural frequency of torsional oscillation is well below the frequency of primary component of oscillating torque, namely, twice pedalling speed. This latter condition should help to reduce cyclic variation of propeller speed and hence to reduce the slight loss of efficiency from this cause.

SOME ASPECTS OF BUFFETING

R. FAIL

To be given on 21st March

Examples are given of a variety of wind tunnel measurements of buffeting.

It is shown that bubble type separations on wings lead to overall aircraft buffeting while vortex type separation need not do so. It is then shown that application of this principle can lead to improved design of air brakes.

Further measurements of the characteristics of air brakes show that changes in the shape have only small effects. Perforations, however, can have large beneficial effects and there is an optimum degree of perforation.

Buffeting in cavities is referred to briefly.

FOURTEENTH LOUIS BLÉRIOT LECTURE

The Development of Short Range Air Transport Through the Use of V/STOL Aircraft

General HENRI ZIEGLER

To be given on 23rd March

The Lecture is in three parts; Part I establishes the criteria for the development of the short range air transport as:—(*i*) *Speed*, which must be above 200 kts. (230 m.p.h.) but must avoid the complications involved in high speed flight; (*ii*) *Flexibility of operation* which will require many small airfields with minimum ground facilities; there are many in Europe which could be used commercially by aircraft capable of operating from grass strips some 2,000 ft. in length; (*iii*) *Reliability*—slow approach speeds permitting steeper angle of descent should simplify the landing aids problem and vertical landings might be achieved by simple systems associating a radio marker with a radio altimeter; (*iv*) *Safety*—one of the main factors for increasing short range traffic; (*v*) *Economy*—a formula is put forward for an aircraft of 30,000 - 50,000 lb. estimating costs in decimal pence per seat mile, taking into consideration the devices required to achieve the slow speed flight necessary for short range operations.

In Part II various methods of achieving V/STOL, all of which are based on an increase in lift, are considered and are classified as (*i*) low-wing aircraft, (*ii*) aircraft using Boundary Layer Control, (*iii*) convertible aircraft and (*iv*) jet lift. Examples are given of the most successful types in each category which have been tested so far. Power requirements for V/STOL aircraft are considered and the various configurations for a 50 passenger project compared. The Lecturer believes that at the present time the propeller-driven convertible STOL aeroplane offers the best solution.

In Part III some of the work done in France on the deflected slipstream transport aircraft and the Breguet "94" types are described; some of the problems encountered and their solutions are outlined, including performance, stability and control, safety and operation, and the development programme which culminated in the Breguet 941 which is due to fly in a few months time.

In conclusion the Lecturer believes that developments in STOL and VTOL aircraft will, in the near future, give a practical, safe and economic answer to the need for fast local traffic, opening up an enormous potential market in air transport and affecting not only the airlines but the economy of the world and also entailing radical changes in military strategical and tactical concepts.

Rotorcraft Section

DEVELOPMENT OF STABILISING EQUIPMENT FOR HELICOPTERS

P. D. MacMAHON

To be given on 2nd June

Auto-stabilisation and the helicopter is briefly discussed, together with comment on features that are desirable in an automatic system *i.e.* reliability, limited auto control authority, maintenance and so on.

Some of the reasons for selecting the Lear A.S.E. system for the Wessex helicopter, and brief terms of reference for its anglicisation and integration are explained. A description of the system is given, indicating the manner in which error signals are derived in the pitch-roll-yaw and altitude axes. A short description is made of the anglicised power controls. Interesting features of the auxiliary hydraulic and electrical servo motors are detailed and their importance in relation to closed loop performance is outlined.

The need to test A.S.E. components, Electronic, Electrical and Mechanical at various stages of integration are discussed. The relative emphasis applied in each area at the beginning of the development programme and the present time are outlined. The need for special test equipment and its development are discussed. The need for realistic test specifications that ensure the utilisation of sub-contracted A.S.E. components, without lowering standards that are necessary for adequate flight performance and airworthiness are discussed.

Certain types of simulators and ground rigs that were found necessary during the development period are discussed. An electrical systems development rig with unusual features is mentioned, with special reference to its use in establishing installation criteria and endurance testing of Wessex helicopter electrical components. The merits of dynamic and static structures for this work are briefly mentioned.

Flight testing and some of the important aspects that arise from it are commented on. The manner in which pilots carry out pre-flight checks and its merits are discussed, together with the reasons for changes in thinking during and after various stages of developments. The need for realistic quality control in important areas of the aircraft's build that affect closed loop performance are outlined. The manner in which work "pyramids" at the flight testing stage is referred to. Qualitative and quantitative methods of performance checking and some of the pitfalls that may arise by addiction to a "single-minded" approach are discussed.

The flying hours needed to obtain adequate performance with Lear A.S.E. electronic components are compared with the approximate flying hours to obtain compatible performance with the anglicised A.S.E. components.

The methods used to determine performance, various types of instrumentation and the reasons for their use are discussed. Performance of the A.S.E. at different forward speeds is demonstrated. In conclusion reference is made to the in-flight reliability with the anglicised system.

DIRECT ELECTRICAL POWER GENERATION BY THERMAL AND CHEMICAL MEANS

PROFESSOR M. W. THRING

To be given on 11th April

Electricity has been generated from fuel for many years by the steam cycle and is now being generated from nuclear fission by this cycle, but the overall efficiency of all cycles involving steam is limited by the upper temperature T_1 at which the bulk of the heat is absorbed.

T_1 is fixed by the need to pass heat through and act upon rigid metal walls and by the temperature pressure relation for the liquid water steam system. There are three possible groups of methods by which these limitations could be overcome. The first is the *fuel cells*. At present a great deal of work is being done on low temperature fuel cells below 300°C and medium temperature fuel cells in the 600-800°C range. Work on fuel cells in the 1,200-1,500°C range and on gas phase fuel cells in the 2,000-3,000°C range could be of considerable interest. *Thermoelectric systems* involve either, (*i*) the use of semi-conductors in the solid state as thermocouple systems with a series of heated hot junctions and cooled cold junctions, or (*ii*) the thermionic emitter. The thermocouple system is limited primarily by conduction of heat through the solid from the hot junction to the cold junction, and the efficiency depends upon the parameter $z = \alpha^2 6/K$ where α is the thermoelectric power in volts per °K. K is the thermal conductivity in Watts/cm°K, and z is the specific conductivity in mhos/cm. The best values of z attainable at present limit the efficiency of this system to about 11 per cent. The other type of thermo-electric system is the thermionic system where one electrode is heated and the other one cooled, and the space between them is either evacuated or filled with caesium vapour at low pressure. This requires very high temperatures for the high temperature electrode, and while at present the overall thermal efficiency is limited, it might be of interest in combination with a semi-conductor thermocouple system. The third type of direct electric power generation is the *electromagnetic gas-braking or M.H.D.* in which a very high velocity stream of high temperature gases is passed through an alternating or direct current magnetic field and slowed down so that part of the kinetic energy is converted into current flowing to electrodes at right angles to the flow and the magnetic field. Pilot plants for this system have been built and operated in America, but the essential difficulty is to obtain a sufficiently high gas conductivity after the gas has been cooled by the adiabatic expansion necessary to give the high velocity. Methods proposed for overcoming this difficulty are (*i*) the use of a striated system with alternate layers of high conductivity gas and comparatively low temperature working fluid, (*ii*) the use of pulsating combustion to give combustion at effectively constant volume instead of constant pressure, and (*iii*) a double shock wave system giving brief pulses of current in opposite directions, as the shock wave passes from one end to the other of an exploding system through a magnetic field in the centre. Some possible aeronautical applications of the third of these methods are considered.

Historical Group

REBUILDING AND FLYING HISTORIC AEROPLANES

Air Cdre. A. H. WHEELER

Given on 9th January 1961

This lecture was preceded by a part of a Shell Film showing Historic Aeroplanes of the Shuttleworth Trust in flight, also some of the pioneers flying in the early days.

WHO WERE THE PIONEERS?

Two of the lesser known pioneers were described—themselves and their work. There was the engineer-mechanic, Mr. Phillips of Shropshire, a bicycle maker and a repairer of motor cars. His design was a classic of good engineering and mechanical perfection but the design was far ahead of the scientific capabilities of the time—1908-1914.

There was also Mr. Frost, one-time President of the Royal Aeronautical Society. His design, flapping wings and eagles feathers driven by a steam engine represented much of the dilettante thinking of that time. The engine was of good design for the time and quite a lot of good scientific thought went into the ornithopter structure but could it ever have taken off? The story is that, after a lunch party in 1886, it ran across a field and hit a hedge 10 ft. up in the air.

What materials did these two pioneers have? Wood, mild steel, carbon steel, Irish linen (or eagle's feathers) bicycle parts. There was no "dope" as we know it and aluminium was a new metal still almost unalloyed. Perhaps it was fortunate for the pioneers that the aluminium was unalloyed, although they used little of it.

MODIFICATIONS WHEN REBUILDING?

In the Shuttleworth Trust modifications are only permitted when they are *needed* for safety, reliability or durability. If a nut had no locking device we would include one but, in fact, the pioneers in this century were generally very well aware of the need for keeping things done up tight. If excessive wear occurred on some fitting we might consider arranging better lubrication or bearing material because of the safety aspect. For durability we protect against corrosion and general deterioration due to damp and we use modern dope instead of the various mixtures which the pioneers had to use with no lasting qualities at all. It would not be a practical proposition to use (say) white of egg or boiled sago an an aeroplane which gives public flying demonstrations regularly.

None of these modifications affects in any way the flying qualities of the historic aeroplane.

THE BLÉRIOT REBUILD

This was described from the first discovery of it on a scrap heap to the flying of it as it is now. Its flight handling characteristics were also described. That was a typical rebuild. Other aeroplanes described were the Blackburn Monoplane, oldest British aeroplane still flying: the Bristol Fighter with its attendant Hucks Starter: the Avro 504 K: the Sopwith Pup: the S.E.5a.

CONCLUSION TO LECTURE

Why do we rebuild and fly—or even keep—historic aeroplanes? For the education and inspiration of the younger generations. The most important characteristics to be learned from the successful pioneers are determination and persistance, not only in surmounting technical difficulties but ever more in carrying on in spite of public disinterest, and ridicule and discouragement from their friends and the public. But for that trait in human nature which induces so many to discourage the very few who work for advancement on original lines, powered flight would probably have been achieved 25 years earlier; gliding might have been achieved 3,000 years before.

Two other reasons for preserving historic aeroplanes and showing how they flew were quoted:

Disraeli said:

> "Great deeds are great legacies and work with wondrous usury. By what man has done we learn what man can do and gauge the power and prospects of our race."

Mark Pattison said:

> "A man who does not know what has been thought by those who have gone before him is sure to set an undue value upon his own ideas."

CHANGES OF ADDRESS OR APPOINTMENT

To assist in keeping the records of members correct and up to date the Secretary will be glad if all members will notify him as soon as possible of changes of address. He would also like to know of any change of appointment.

When notifying changes please give the following particulars:—

Name (in block letters)	Grade of Membership
New Address (in block letters)	Old Address

New appointment.—Please give name and address of employer and position held, and former appointment.

Changes of address must be received *before the 15th of the month* in order to be effective for the following month's JOURNAL.

The Journal of the Royal Aeronautical Society

INCORPORATING THE INSTITUTION OF AERONAUTICAL ENGINEERS AND THE HELICOPTER ASSOCIATION OF GREAT BRITAIN

VOLUME 65 MARCH 1961 NUMBER 603

The Fourth Lanchester Memorial Lecture

British Universities and Aeronautical Research

BY

Professor A. D. YOUNG, M.A., F.R.Ae.S., A.F.I.A.S.

(*Professor of Aeronautical Engineering, Queen Mary College, University of London*)

SUMMARY: Some remarks are first made on the pertinence of the topic chosen for a lecture dedicated to Dr. Lanchester. A brief historical review is then given of the development of University teaching and research activities in Aeronautics from the early years of the century to the present. An imaginary but typical modern University Department of Aeronautical Engineering is described with particular reference to numbers of students, staff, laboratory equipment and budget. Some of the many research topics to which the Universities have made and are making important contributions are then discussed briefly. These are to illustrate the scope and tendencies of University research against the background of current developments in Aeronautics. Among the subjects referred to are such topics as the structure of the turbulent boundary layer and the measurement of skin friction, flow separation phenomena, boundary layer drag and heat transfer at high speeds, aeroelasticity, the application of matrix methods to structural analysis using digital computers, structural damping, secondary flows in propulsion machinery, the rotating stall and jet noise.

The paper concludes with some general remarks on the relationships between the Universities, the Government Research Establishments and the Industry and on the future of University research. The importance of maintaining on the one hand the independence of the Universities and on the other hand the closest contact between them, the Government Establishments and Industry is strongly emphasised.

The Fourth Lanchester Memorial Lecture—the first Named Lecture to be given in the new Lecture Theatre—"British Universities and Aeronautical Research," was given by Professor A. D. Young, M.A., F.R.Ae.S., A.F.I.A.S., on 22nd December 1960. Dr. E. S. Moult, C.B.E., B.Sc.(Eng.), F.R.Ae.S., M.I.Mech.E., President of the Society, presided.

Introducing the Lecturer Dr. Moult said that the Lanchester lectures were initiated by the Society in 1957 as a memorial to Dr. F. W. Lanchester who died in 1946. They were privileged to have with them that night, doing honour to this great name of Lanchester, his brother, Mr. George Lanchester. They very much regretted that Dr. Lanchester's widow, Mrs. Lanchester, was unable to be present: she had been in the past and they hoped to see her on future occasions.

Dr. Lanchester achieved fame as an engineer with interests both in aeronautics and in the automobile field; he was the first to appreciate the need for a scientific basis to mechanical flight and from this beginning had sprung the vast science of aerodynamics.

There was no one more suited to give a lecture on Aeronautical Research in British Universities than Professor A. D. Young, Professor of Aeronautical Engineering at Queen Mary College, London.

Professor Young was a Cambridge man who studied aeronautics under Professor Sir Melvill Jones. In 1936, he joined the Royal Aircraft Establishment where he entered the Aerodynamics Department. In 1946, Professor Young became Senior Lecturer at the R.A.E. College of Aeronautics, and later, Deputy Head under Professor W. J. Duncan, whose unexpected death a short time ago had come as a shock to many of them and who was a great loss to aeronautics. In 1954, Professor Young was elected to the chair of Aeronautical Engineering at Queen Mary College, University of London; he was a Fellow of the Society.

1. Introduction

It is always an honour to be invited to deliver a Lecture to this Society; when the Lecture is as in this case dedicated to the memory of a very great man and follows Lectures such as those of my distinguished predecessors Professor von Kármán, Professor Collar and Professor Schlichting then the honour is indeed a signal one. I appreciate it deeply although I am acutely aware of my own shortcomings for the task that is set me.

What connection is there between the man to whom this Lecture is dedicated and my subject? At first sight such a connection might seem difficult to establish since Dr. Lanchester did not attend a University nor did he teach at one. He was indeed one of the last of the great British Scientific geniuses who by an historical accident managed to avoid being educated on standard conventional lines but who nevertheless in due course generated the ideas which provide the foundations of much of modern industrial and scientific thought, ideas which

are now well embedded in the fabric of University teaching. He left school in 1882 at the age of fourteen and then went to study engineering at the Hartley Institute, the forerunner and embryo of present day Southampton University. After two years he won a scholarship to the Normal School of Science, later to become the Royal College of Science and part of Imperial College, London University. George Lanchester[1] in a lecture to the Newcomen Society tells us that his brother found the curriculum at the Normal School inadequate in applied engineering and this deficiency he made good by attending evening classes at Finsbury Technical College. We are also told that he deliberately failed his third year examinations in order to spend a further year perfecting a telescope that he was building. One can only wish that some present day students that fail their examinations could produce equally good reasons! Dr. Lanchester's only formal connection with a University was, I believe, later with Birmingham University where he was an external examiner for a few years and was awarded an honorary degree of LL.D. in 1919. However, although Lanchester's contacts with Universities were slight he was nevertheless clearsighted enough even in those early days to say in his Introduction to the 1907 Edition of his book *Aerodynamics*[2]:—

"In order that real and consistent progress should be made in Aerodynamics and Aerodonetics, apart from their application in the engineering problem of mechanical flight, it is desirable, if not essential, that provision should be made for the special and systematic study of these subjects in one or more of our great Universities, provision in the form of an adequate endowment with proper scope for its employment under an effective and enlightened administration.

"The importance of this matter entitles it to rank almost as a National obligation . . ."

This quotation, I hope, establishes my subject tonight as appropriate to a Memorial Lecture dedicated to him.

If I need any other excuse for choosing this particular topic I would like to mention an interesting historical fact, namely, that the first University establishment in this country at which there was organised research and teaching in Aeronautics was my College, Queen Mary College, or East London College as it was then known. Here I would like to pay a tribute to another great pioneer of British aeronautics, Dr. A. P. Thurston. After graduating from the College in 1905 Dr. Thurston established there round about 1908 an Aeronautical Laboratory, financed largely from his own pocket and that of a close friend of his, Mr. Y. P. Alexander. Wind tunnels were built and lectures were given and Fig. 1 shows a handbill advertising some of the lectures. Research investigations were made into the aerodynamic properties of aerofoils and struts and related structural investigations were also made. Some of the work before and during the First World War was done under the aegis of the newly formed Advisory Committee for Aeronautics, of which Dr. Lanchester was for some years a member. This committee later became the Aeronautical Research Council. Dr. Thurston was able to attract around him a group of enthusiasts for aeroplanes and for the study of aeronautics, and later they formed a valuable body of trained engineers and scientists to meet the country's needs in building up our air power in the First World War. Dr. Thurston himself was appointed to the War Office at the outbreak of the War to take on the task of formulating the design requirements of military aircraft and he left in charge of the College Laboratory his senior assistant Dr. Piercy. Dr. Piercy remained Head of the Department of Aeronautical Engineering (as it subsequently became) until his death in 1953. I am proud to have succeeded him as Head of a Department so well founded and with such a long history.

At this stage I would like to summarise the ground I hope to cover in the remainder of this paper. I shall begin with a very brief historical review of the growth of University teaching and research activities in aeronautics and related disciplines from the early years of the century to the present. I shall follow this with a

EAST LONDON COLLEGE.

(University of London.)

MILE END ROAD, E.

Syllabus of Three Lectures on "Aeronautics"

TO BE DELIVERED BY

Mr. A. P. THURSTON, B.Sc. Lond., M.Aero. Soc., Gt. Bn.,

(Late Assistant Engineer to Sir Hiram Maxim.)

1st LECTURE.—Monday, June 14th, 1909, at 8 p.m.

"FLYING MACHINES (Heavier than Air Type.)"

Chairman—SIR HIRAM S. MAXIM.

The development of the art by Besnier, Henson, Wenham, Maxim, Langley, Lilienthal, Pilcher, Chanute, Herring, Santos Dumont, Bleriot, Farman, Delagrange, and the Wright Brothers. Types of Machines: (1) Aeroplanes, (2) Helicopters, (3) Aviplanes: their relative possibilities. Monoplanes, Biplanes, Triplanes, etc. Methods of trimming, steering and of obtaining stability. The construction of the Voisin, Wright and Bleriot machines. Recent patents of the Wrights. Engines: Maxim, Renault, Matzinger, Gnome, Golron, Antoinette, J.A.P., Green, etc. The Glide Angle. Horse power for flight. The future.

The lecture will be illustrated by Lantern Slides, Experiments, and Models of the Wright, Farman and Bleriot Machines.

2nd LECTURE.—Wednesday, June 23rd, 1909, at 8 p.m.

"BALLOONS, AIRSHIPS AND KITES."

Chairman—SIR CORNELIUS N. DALTON, K.C.M.G., C.B., *Late Comptroller General, H.M. Patent Office.*

The development of the art by Lana, Montgolfier Brothers, Charles and Green. Early journeys and the invasion of England. Records for height and distance. The modern Balloon: Materials. Methods of Steering. The Parachute. The Dirigible Balloons of Meusnier, Giffard, Haenlein, Renard, Santos Dumont. Modern Battle Airships: Nulli Secundus, La Republique, Von Gross-Parseval, Zeppelin. The Non-Rigid, Semi-Rigid and Rigid Dirigible Balloons: Construction and Theory. The Future Possibilities in Peace and War. Box Kites. Teams of Kites. The Kites of Baden-Powell, Cody and Parseval.

The Lecture will be illustrated by Lantern Slides and by CINEMATOGRAPHS *of the Wright Machine, the Farman Biplane and Triplane. The French Military Airship, La Republique, and the German Military Airship of Count Zeppelin.*

3rd LECTURE.—Wednesday, June 30th, 1909, at 8 p.m.

"THE MECHANICAL PRINCIPLES OF FLIGHT."

Chairman—MAJOR BADEN-POWELL, F.R.A.S., F.R.Met.Soc., *Vice President Aero. Soc., Great Britain.*

Birds, Beating and Soaring Flight. Power in Flying, Rapidity of Flapping. Methods of Powerless Flight. The Mechanical Representation of Bird Flight. The Aeroplane and Aerocurves. The Centre of Pressure, Aspect, Coef of Skin-Friction, Coef of Resistance. The Propeller. The Helicopter. The importance of dealing with Undisturbed Air. Gliders. Stream Line Surfaces. Theories applied to Modern Machines. The Equations of Flight or Phugoids. Equations of Stability. Automatic Stability. Laboratory Experiments. Whirling Tables and Wind Tunnels. Apparatus of Langley, Maxim, etc. The necessity for research.

The Lecture will be illustrated by Lantern Slides and Experiments.

Applications for Tickets of Admission to the above Lectures should be sent to the Registrar at the College.

The College is situated in the Mile End Road, and is within a few minutes' walk of the following Railway Stations:—Stepney (District Railway), Globe Road (G.E.R.), Bow (N.L.R.). Motor Omnibuses from the City, West End and South London via Aldgate pass the College.

FIGURE 1.

description of a typical modern University Department of Aeronautical Engineering. I then propose to illustrate what Universities are now doing by discussing a few of the research topics to which they have made and are making important contributions. I shall finish by some general comments on the relationships between the Universities, the Government Research Establishments and the Industry. As the title indicates I shall be concerned solely with British Universities and British aeronautical research; in other countries the pattern of research organisation is different in many essentials and it would take at least another lecture to discuss and compare these patterns. The research activities that I have chosen to illustrate this paper are only a small sample of the many that I could have chosen, they largely reflect my own interests and therefore are not necessarily the most important; nevertheless I hope that they are sufficiently representative for my purpose.

2. Historical Review

2.1. UP TO THE SECOND WORLD WAR

In the First Lanchester Memorial Lecture Professor von Kármán[3] referred to Lanchester's remarkably intuitive and generally accurate approach to the problems of aircraft stability as set out in his book *Aerodonetics*[4]. Lanchester's description of the longitudinal phugoid motion, an approximation to what is now referred to as the long period mode, is well known; what is perhaps less well known is his interesting description of the lateral spiral mode which he called "rotative stability." However, he used little mathematics and the subject therefore called for the development of a general theory in mathematical form. Such a theory was provided by Professor Bryan of Cardiff University when in 1911 he published his famous book *Stability in Aviation*[5]. Modern stability theory has been built on the solid foundations of Professor Bryan's work, which in essentials is as valid today as ever. As Professor Lighthill[6] pointed out in his Wilbur Wright Lecture, Professor Bryan's great contribution was his exposition of the importance of stability derivatives.

The First World War hastened the pace of aeronautical development and saw the development of the Royal Aircraft Establishment, some rapid growth in the Aerodynamics Division of the National Physical Laboratory and in the importance of the Aeronautical Research Committee. At the same time the need for the establishment of University Departments of Aeronautics was clearly recognised and in 1919 the Francis Mond Chair at Cambridge was established, followed by the Zaharoff Chair at Imperial College in 1923. To the former was appointed B. Melvill Jones and to the latter L. Bairstow, both of whom had by then established reputations for their work at the N.P.L., Farnborough and elsewhere during the War. About the same time G. I. Taylor who had returned to Cambridge was appointed Yarrow Professor of the Royal Society and he established in the Cavendish Laboratory a Department mainly devoted to problems of Fluid Mechanics, Mechanics of Solids and Meteorology.

Professor Melvill Jones concerned himself largely, but not exclusively, with the measurement and reduction of the drag of aircraft, and his classic paper on "The Streamline Aeroplane"[7] given to this Society in 1929 did more, in my view, than any other single paper to influence the design philosophy of aircraft in the inter-War years. He also developed his famous Pitot-traverse method of measuring the profile drag of wings[8] which for the first time made it possible to determine quickly and accurately the effects of modifications of profile shape and finish. The encouragement that he gave Frank Whittle in his work on the gas turbine when Whittle was a student at Cambridge should not go unmentioned. Professor Bairstow concerned himself with problems of aircraft stability and the spin and made valuable contributions to these subjects as well as to problems of airship flight. I cannot begin to summarise the enormous scope and importance of Professor Taylor's numerous contributions to aeronautics, his publications have recently been collected in two large volumes edited by Dr. Batchelor[54], but perhaps his most important work lies in his studies of turbulence. His investigations laid the foundations of the modern statistical theories of turbulence[9]; and his classic experiments[10] made in 1923 on the formation of vortex cells between rotating cylinders are as pertinent as ever to any discussion of laminar flow stability. Meanwhile Dr. Piercy made a number of important contributions to our knowledge of aerofoil characteristics, techniques of flow measurement and to boundary layer theory, and he developed a family of aerofoil sections of unusual versatility[11].

The only other Chair established in the inter-War years was the Wakefield Chair in Aeronautics at Hull in 1934 to which W. J. Duncan was appointed. Duncan had previously worked at the N.P.L. with Frazer and Collar and their contributions to our understanding of the phenomenon of flutter and aeroelastic effects were of the very first importance to the safety of aircraft. In the Second Lanchester Memorial Lecture[12] Professor Collar gave us an excellent review of this work. Professor Duncan continued these investigations at Hull as well as general investigations into the mechanics of vibrating systems.

Although no other Chair in Aeronautics was established during the period under review, schools of Applied Mathematics were taking an increasing interest in aeronautical problems, notably in aerofoil and airscrew theory, wind tunnel interference and boundary layer theory. Here the contributions of Dr. S. Goldstein, then at Cambridge, and of Professor L. Rosenhead of Liverpool University were of outstanding importance.

Meanwhile at Oxford, Professor R. V. Southwell, then Professor of Engineering Science, perfected a most valuable and versatile tool for tackling a wide range of problems in Fluid Mechanics and Structures by his work on the method of relaxation.

2.2. THE SECOND WORLD WAR AND POST-WAR DEVELOPMENTS

With the outbreak of the Second World War there was an almost complete mobilisation of University

scientific personnel who were concentrated in the first instance in the R.A.E. and the N.P.L. I recall the acute embarrassment of Dr. Douglas, then Head of the Aerodynamics Department at the R.A.E., when he found in his office one morning about six distinguished University Professors who had been allotted to him and he had to find without delay suitable problems for them! It is impossible and would indeed be invidious for me to attempt to disentangle the work of University personnel in Government Establishments from that of their colleagues during the War years. Suffice it to say that their integration into the general War effort was remarkably successful, not less so because they helped to preserve in those difficult years a balanced sense of the relative importance of fundamental and applied research.

During those War years it became very apparent that the country needed a considerable expansion of its resources for the teaching of Aeronautics and the immediate post-War years saw the establishment of Departments of Aeronautical Engineering at Bristol under A. R. Collar and at Southampton under E. J. Richards; in addition the College of Aeronautics was founded at Cranfield under E. F. Relf as Principal. Further, at Manchester the Fluid Motion Laboratory was set up under W. A. Mair, a development that we owe entirely to the enthusiasm and energy of Sydney Goldstein, then Professor of Mathematics at Manchester University. He thereby established a practical complement to his own Department, making Manchester University a most fruitful centre of theoretical and practical research and teaching in all branches of Fluid Mechanics. Subsequently in 1950 the Mechan Chair in Fluid Mechanics and Aeronautics was established at Glasgow, and Professor W. J. Duncan left the College of Aeronautics where he had held the Chair of Aerodynamics to take up this new Chair. More recent developments have been the establishment of a Chair in Aeronautical Engineering at the Queen's University, Belfast, to which Professor A. V. Stephens was appointed, a Chair in Fluid Mechanics at Liverpool to which Dr. J. Preston was appointed, and the Fluid Motion Laboratory at Manchester was converted into a Department of Mechanics of Fluids under Professor P. R. Owen.

To round off this rapid survey of the growth of aeronautical teaching and influence in recent years it is perhaps worth noting that a considerable number of Chairs in other branches of Engineering have been filled by men whose primary training and interests were in aeronautical engineering, interests which in most cases they have not relinquished. I have in mind such men as Sir Alfred Pugsley of Bristol, S. C. Redshaw of Birmingham, C. Gurney of Cardiff, and J. B. B. Owen of Liverpool. We may also note the large number of Professors of Applied Mathematics who have similarly received their research training in aeronautics and have retained a major interest in its theoretical problems. Parallel to these developments there is the tremendous stimulus that Aeronautical Engineering has given to University research in related fields of Engineering as, for example, materials both metallic and non-metallic, electronics, servo-mechanisms and computers.

3. A Typical University Department of Aeronautical Engineering

I have occasionally been surprised by the ignorance in otherwise well informed quarters of the size, potential and general teaching task of a University Department of Aeronautical Engineering. A brief sketch of a typical, if imaginary, Department would not therefore be inappropriate at this stage.

The student intake is about thirty to forty a year, and at any one time there may be between five and ten research students. The aerodynamic equipment includes at least two low speed wind tunnels of good modern design and about 10 to 15 sq. ft. in working section area together with a number of smaller tunnels of simpler construction. There are one or two supersonic tunnels with working sections about 20 to 40 sq. in. in area and sundry small high speed jets, and for hypersonic work there are one or two small shock tubes or a gun tunnel. Where the teaching of Aircraft Structures is the responsibility of the Department, as in the case of my Department, a laboratory of standard structural test equipment is provided and such laboratories will probably include equipment for vibration investigations and investigations of kinetic heating effects. The teaching staff comprises a Professor, a Reader and between three to five Lecturers, and the Department will probably have its own small workshop employing up to half a dozen people.

In general the equipment is as small, simple and cheap as modern research and demonstration needs will permit, but ancillary electronic equipment that is increasingly essential for such needs makes very heavy demands on the annual budget. I suppose that the current allowance to my Department is not untypical, it is £4,500 per annum to cover all the equipment needs; of that sum the research students inevitably take the lion's share. Three or four years ago my allowance was less than a third of this figure and before the War the allowance was about £20! When it is remembered that one good oscilloscope might cost £800 the limitations that economy must impose on University activities will be very apparent.

Here I must pay tribute to the Ministry of Aviation in all its various metamorphoses for the generous way in which it has supported specific items of University research by means of research contracts. Such contracts were rare before the Second World War, but since the War they have become much more common, and most University Departments of Aeronautical Engineering have a small number of research contracts whereby they are able to pay some of the junior research personnel concerned and to buy special ancillary equipment. I believe that at present the Ministry research contracts with Universities on broadly aeronautical topics total about £160,000 per annum. This may seem small relative to American practice, but in the special circumstances that hold in this country, namely the relatively large amount of aeronautical research done in Government research

establishments and the intense concern of the Universities for their independence, this sum is by no means insignificant, except in relation to the return that is made for it. As for the research students they are generally graduates with First or Upper Second Class Honours Degrees, and they are usually in receipt of a grant from the D.S.I.R. of value £340 to £420 per annum. I need hardly say that good research students are becoming increasingly difficult to recruit because of the far superior pay that graduates can obtain in Industry and Government service, and because the status that is conferred on holders of higher degrees in industrial circles in this country is slight by comparison with that conferred in other countries.

Finally, any assessment of the part played by the Universities in aeronautical research must be made bearing in mind not only their limited financial resources but also the considerable demands made on the time and energy of the staff by their rapidly increasing undergraduate teaching commitments and College and University administration needs.

4. Range of Modern Research

Perhaps the outstanding feature of the post-War years has been the rate at which the range of flight speeds and conditions in which we are interested has widened. The jet transport flying at high subsonic speeds is now almost commonplace, the supersonic transport is actively under discussion and is likely to be with us in a decade or so, the re-entry of ballistic vehicles and satellites has brought into active consideration problems of hypersonic flight and related heat transfer problems, and not a little thought is already being given to the possibilities of commercial vehicles travelling at hypersonic and near satellite speeds. At the same time interest in the problems of low speed flight has in no sense decreased, on the contrary the unusual plan forms associated with these more ambitious projects have brought their own special low speed problems as have also the projects being considered for vertical and short take-off and landing (V.T.O.L. and S.T.O.L.). Within these general lines of development the Universities have rightly and naturally confined their activities to research topics of a fundamental and long term nature consistent with the modest resources that they are able to deploy. Let us examine a few of these topics and the contributions that the Universities have made and are making to them.

5. Turbulent Boundary Layer Structure and Skin Friction

I have already referred to the important work of G. I. Taylor[9] at the Cavendish Laboratory nearly thirty years ago whereby he laid the foundations of the statistical theory of turbulence. This established a fruitful basis for theoretical and experimental investigations of the structure of turbulent flow, and the subsequent work of Dr. Batchelor and Dr. Townsend has retained for the Cavendish Laboratory its pre-eminent position in this field. I cannot attempt to summarise their work here but I would like to draw attention to a few salient points that we have learned about turbulent boundary layers from the work of Dr. Townsend[13] and others, points that are relevant to what follows.

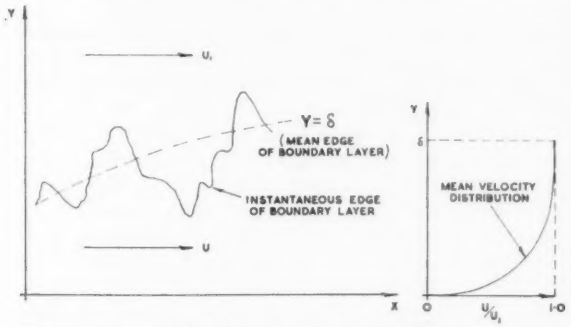

FIGURE 2. Sketch illustrating the intermittent character of turbulence in the outer part of the boundary layer.

If we examine the upper boundary of a turbulent boundary layer at any instant it is found to be irregular as illustrated in Fig. 2 due to the presence of large scale eddies of dimensions comparable to the width of the boundary layer in the outer part of the layer. Within the body of the layer the linear scale of the turbulence is in general much smaller. Although the turbulent energy of these large eddies is relatively small they play a vital part in controlling the entrainment of fluid from outside the boundary layer and therefore in the rate of growth of the layer. Investigations of the balance of energy of the turbulence near the wall show the largest factors to be a gain of energy from the mean flow due to the work of the mean flow against the eddy or Reynolds stresses and a loss of energy due to viscous dissipation. Close to the wall these two factors almost exactly balance, the former being slightly larger. However, the small difference between these two factors is important because it is diffused upwards from near the wall to the outer parts of the boundary layer and ultimately provides the energy of the large eddies there. Thus, the motion in the outer parts of the layer depends on the flow development for some considerable distance upstream and is slow to respond to changes at and close to the wall. Near the wall, on the other hand, the flow is dominated by the presence of the wall and by the local wall shear stress and it adjusts itself quickly to local changes there but is not directly influenced by the flow outside the boundary layer. It seems that the large eddies in the outer region arise from some instability of the flow close to the wall, but the mechanism for this is still not fully understood although interesting hypotheses have been put forward by Dr. Townsend[13, 14] and his colleagues.

Now for a long time an accepted simplified picture of the turbulent boundary layer, based largely on dimensional reasoning and measurements of mean velocity distributions, has been one in which it has been divided into two regions, excluding the laminar sub-layer, an inner region and an outer region. In the inner region, about a tenth of the layer in thickness, in which the shear stress is nearly constant, the important parameters have been

taken to be the local wall shear stress (τ_w), kinematic viscosity (ν) and the distance from the wall (y), while in the outer region the external stream velocity (u_1) and the boundary layer thickness (δ) are important. The flow in the inner region is assumed to be independent of the flow outside the boundary layer and in particular of the external pressure distribution, while in each region the structure of the flow is assumed to have a measure of dynamic similarity and to that extent to be independent of its past history. The detailed investigations of the structure of the turbulent boundary layer, such as those of Dr. Townsend, clearly lend some support to this simplified picture but also help us to understand its limitations. Thus a relatively slow rate of change of wall shear stress with distance along the wall is implied by the assumed independence of past history, and this indicates that the deductions will be less in doubt at high than at low Reynolds numbers. Further, the nature of the coupling between the two regions of flow although loose is such that we cannot always rely on deductions based on the assumption that the inner region is independent of the outer flow.

Dimensional analysis, measurements of mean flow and semi-empirical theories all agree in the velocity distribution in the inner region taking the well-known logarithmic form (the so-called " law of the wall ")

$$u/u_\tau = A \log\left(\frac{yu_\tau}{\nu}\right) + B \quad . \quad . \quad (1)$$

where $u_\tau = \sqrt{(\tau_w/\rho)}$, ρ is the density and A and B are constants.

However, if there is general agreement on the form of the " law of the wall " it must be noted that different experimenters are not in complete accord as to the values to take for A and B in equation (1). Values of A are variously quoted between 2·2 and 2·9 and values for B range from 4·0 to 7·15, although values that have wide acceptance are 2·5 and 5·5 respectively. In part these differences are likely to be due to experimental inaccuracies since the accurate measurement of the wall stress is very difficult; nevertheless from the evidence that I have already referred to and other experimental work[15] it seems that the quantities A and B are not completely independent of external flow conditions and of the Reynolds number. This suggests that for refined analysis the concept of two separate and independent regions is not quite adequate except at very high Reynolds numbers and in small external pressure gradients. However, Professor Preston[16] made the interesting deduction that if the " law of the wall " were truly universal then from one calibration, readily obtained from experiments in a pipe, it should be possible to determine the skin friction on a wall, whatever the external pressure distribution, from a simple reading of the total pressure registered by a Pitot tube in contact with the wall and of sufficiently small diameter to be immersed in the inner region. This result is of considerable potential value since it is otherwise extremely difficult to obtain directly local skin friction values. Professor Preston demonstrated that he could obtain a unique calibration for flow in pipes and that it gave consistent results for different sizes of Pitot tubes on a wall. However, other workers[15, 17] have since demonstrated that for flow past a plate the calibration is slightly different from that for pipe flow, the differences being associated with the different values of A and B found in the two cases. The skin friction values deduced from these different calibrations can differ significantly (up to 15 per cent). Nevertheless, it will be clear that to apply this remarkably simple method to a wide range of practical problems we need only determine a few basic calibration relations of the type determined by Professor Preston for pipe flow. The possibility of applying the technique to three-dimensional boundary layers has still to be explored; if it can be applied to such cases its value will clearly be enormously enhanced.

6. Mixing Processes, Separation, " Bubbles " and Vortices

It has sometimes been argued that much of the fundamental work on turbulence and the structure of the turbulent boundary layer to which I have referred is highly academic and, by inference, is of no real practical value. Against this argument I would point out that such investigations are essential if we are to understand the nature of turbulent mixing, and there is scarcely any engineering application involving the motion of fluids which does not involve a process of turbulent mixing. Therefore the ultimate practical importance of these studies cannot be too strongly stressed. Because of the need for a better understanding of turbulent mixing many University laboratories are currently investigating various aspects of this problem. For example, in the Aeronautical Laboratory at Cambridge the behaviour of a two-dimensional jet near a curved wall is being investigated; in my own Laboratory a student is examining the flow in and near a two-dimensional jet directed downstream in a wind tunnel with varying degrees of tunnel turbulence and external pressure gradient; at Imperial College the research programme includes investigations of a circular jet at various angles to the main stream[18] and comprehensive investigations of supersonic jets[19] as well as jets impinging on plane surfaces are being made at

FIGURE 3. Pressure distribution on wing with short and long bubbles (McGregor 1954).

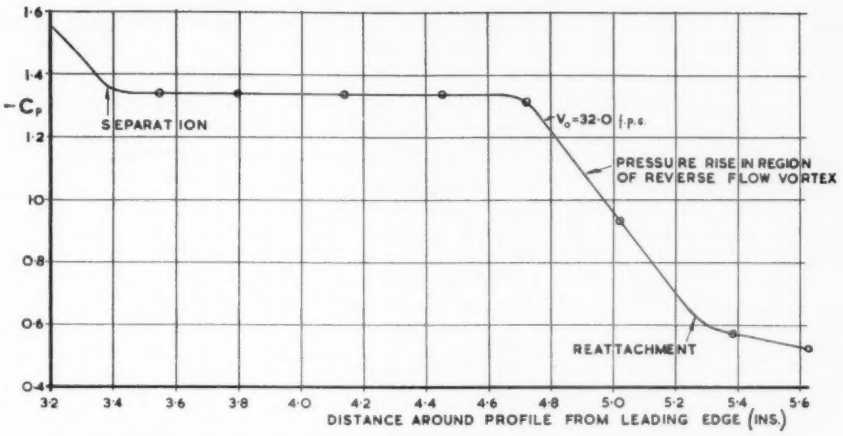

FIGURE 4. Pressure distribution in region of short bubble (McGregor 1954).

Manchester. The interaction of jets with neighbouring wings and bodies in connection with jet lift and jet flaps is also receiving attention at various Universities.

Obviously important processes involving the mixing of adjacent fluid streams moving at different speeds are those of flow separation and reattachment. Dr. Küchemann has said that we must learn to live with separation since it can be regarded as a regular and not necessarily bad feature of the normal flying conditions of many types of modern aircraft. But if we wish to live in harmony with a spouse of somewhat uncertain temperament we must clearly do what we can to understand that temperament. To this end we find that workers in almost all the relevant University Departments in the country are engaged in research on some aspects of separation. I would like to discuss a few salient points of interest that have emerged in recent years.

If we consider the thin wing sections of current usage we find that at incidence the boundary layer in an initially laminar state readily separates from near the nose and then reattaches to form a so-called bubble. We distinguish between short and long bubbles, the former are usually not more than one or two per cent of the chord in length and their effect on the flow and pressure distribution is very localised, the latter can extend over a considerable fraction of the wing chord and their effect on the pressure distribution is marked and extensive, as illustrated in Fig. 3. A reduction of Reynolds number or an increase of incidence can make a short bubble change into a long one, and either type can be

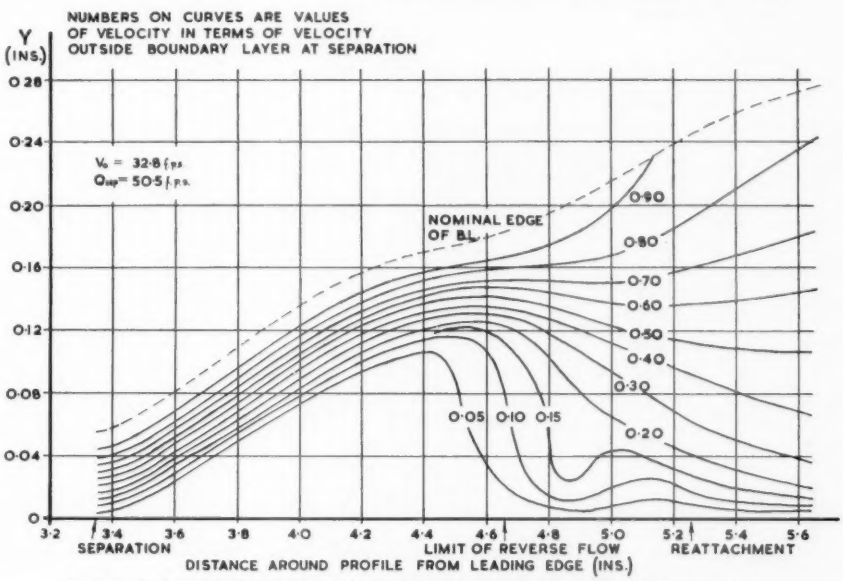
NUMBERS ON CURVES ARE VALUES OF VELOCITY IN TERMS OF VELOCITY OUTSIDE BOUNDARY LAYER AT SEPARATION
Y (INS.)
V_o = 32·8 f.p.s.
Q_{sep}= 50·5 f.p.s.
NOMINAL EDGE OF BL
SEPARATION
LIMIT OF REVERSE FLOW
REATTACHMENT
DISTANCE AROUND PROFILE FROM LEADING EDGE (INS.)

FIGURE 5. Iso-velocity contours in region of separation bubble (McGregor 1954).

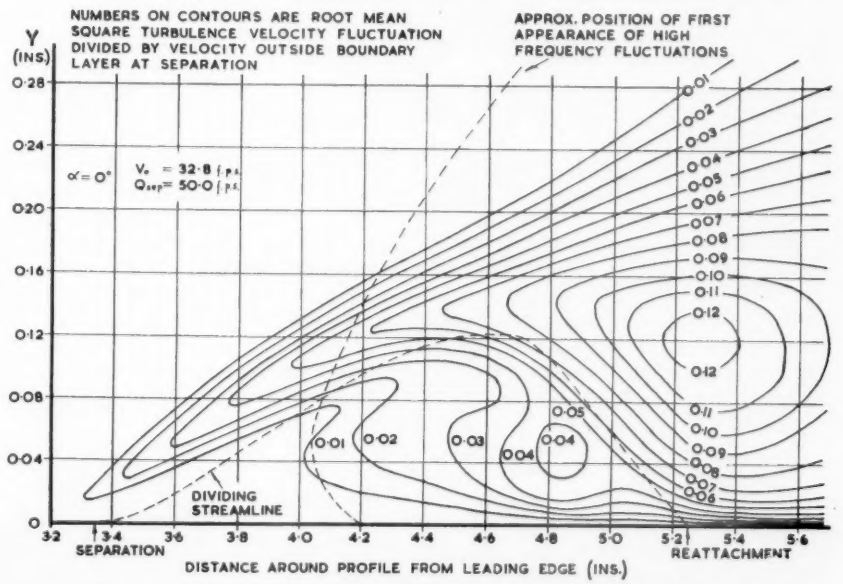
NUMBERS ON CONTOURS ARE ROOT MEAN SQUARE TURBULENCE VELOCITY FLUCTUATION DIVIDED BY VELOCITY OUTSIDE BOUNDARY LAYER AT SEPARATION
APPROX. POSITION OF FIRST APPEARANCE OF HIGH FREQUENCY FLUCTUATIONS
Y (INS.)
α= 0°
V_o = 32·8 f.p.s.
Q_{sep}= 50·0 f.p.s.
DIVIDING STREAMLINE
SEPARATION
REATTACHMENT
DISTANCE AROUND PROFILE FROM LEADING EDGE (INS.)

FIGURE 6. Contours of equal measured velocity fluctuations (McGregor 1954).

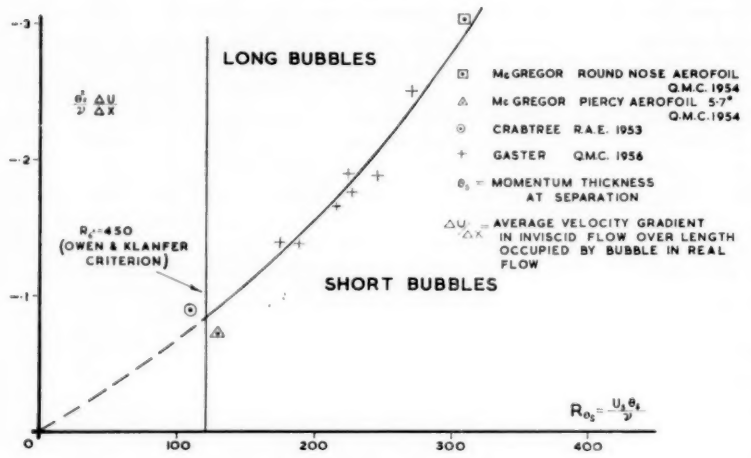

FIGURE 7. Criterion for transition between long and short bubbles (Gaster).

provoked into "bursting," and then the downstream flow is completely separated from the wing surface. A detailed study of short bubbles was made a few years ago at my College by Dr. McGregor[20] who was then a research student and some of his results are illustrated in Figs. 4, 5 and 6. Typically, the pressure in the forward part of the bubble is constant and the air is almost at rest there, but towards the rear of the bubble there is a region of rapid pressure rise and in this region there is a strong vortex in which the velocities are by no means small. Fig. 5 shows a typical set of iso-velocity lines, the vortex at the rear is clearly evident as is the sudden thickening there of the separated shear layer just before reattachment. Fig. 6 shows a corresponding plot of contours of intensity of turbulence fluctuations and we note the transition to turbulent flow in the separated shear layer just ahead of the vortex. This is presumably why the layer subsequently thickens rapidly and is able to reattach to the surface. The region of intense turbulence just at reattachment is noteworthy. Similar detailed studies for long bubbles are planned; some recent preliminary investigations on such bubbles showed, as might be expected, a more gradual thickening of the shear layer towards the rear and a correspondingly more gradual pressure recovery.

The factors that determine whether a bubble will be short or long are obviously of importance and an early analysis of available data by P. R. Owen and L. Klanfer[21] led them to suggest that if the Reynolds number of the boundary layer at separation based on the displacement thickness and local velocity was less than about 450 then the bubble would be long, for greater values of this Reynolds number the bubble would be short. It seems likely that the stability of the separated boundary layer and hence the rapidity of reattachment should depend on such a Reynolds number, but a detailed analysis of more recent data by M. Gaster, a research student at my College, suggests that this criterion is not by itself enough and that a parameter involving the pressure rise negotiated over the rear of the bubble is also required. His analysis has led him to suggest the empirical curve of Fig. 7, separating long and short bubbles in which the ordinate involves the average velocity gradient in inviscid flow over the length occupied by the bubble in the real flow. Other factors of importance may be revealed when further data are available and much work of fundamental interest on bubbles remains to be done; current work in various University departments includes the investigation of the effects of sweep, compressibility[21] and the bubbles associated with forward and rear steps.

Leaving the topic of bubbles, let us now turn to the subject of separation from highly swept leading edges and the associated vortex sheets and vortices. Although much important work has been done on this topic at the R.A.E. and N.P.L. we have also learnt a great deal as a result of the work of Mr. Fink[23, 24] at Imperial College, Dr. Black[25] at Bristol, Mr. Elle[26] at Southampton and by Mr. Marsden[27] and others at the College of Aeronautics. The general features of such flows are now too well known for me to need to discuss them here, but of particular interest is the fact that the leading edge vortices can persist for a considerable distance without diffusing rapidly, in spite of the fact that the flow in these vortices must be turbulent. However, when they do eventually begin to diffuse they do so rapidly, and the point at which this begins moves upstream with increase of incidence so that at large incidences this rapid diffusion can occur ahead of the wing trailing edge. At this stage the flow becomes unsteady and buffeting appears, hence it is important to know what determines the onset of rapid diffusion of the vortices. Work on this problem is currently proceeding at Imperial College under Professor Squire. A theoretical analysis of his[28] shows that under certain conditions the vortex is unstable to long waves, and these conditions approximate to the experimental conditions when rapid diffusion has occurred. A contribution to this problem has also been made by Dr. Jones[29] of Southampton. Another important aspect of this problem on which work is proceeding in various University Laboratories, notably at Southampton, Imperial College and Cranfield, is the effect of sideslip and yaw on the flow pattern and stability.

7. Boundary Layer Control

From flow separation one is led naturally to the subject of boundary layer control, and to this latter subject major contributions have been and are being made at Cambridge. The results of the post-War experimental and theoretical work of Professor Sir Melvill Jones and Dr. M. R. Head[30], coupled with that of Dr. Lachmann[31] of Handley Page Ltd. and his team, have made it clear that the principle of achieving extensive regions of laminar boundary layer flow by suction is

sound and that the laminarised aircraft is a practical possibility offering significant economic gains for medium and long range transport. While research problems remain, for example more information is needed on the effects of leading edge sweep at large Reynolds numbers, it seems that the next stage is to build an aircraft on which we can " suck it and see " so that the reliability of suction techniques under operational conditions can be thoroughly assessed. It should be emphasised that this work may have important applications to supersonic as well as subsonic aircraft, and this is a field to which we may expect University laboratories to contribute in the future.

The considerable amount of work that is being done in the Government establishments on boundary layer control for high lift by blowing was described by Dr. J. Williams in a paper in March 1960[32]. As a complement to this work Professor Mair and Dr. Head at Cambridge are investigating the use of suction for high lift. Their programme includes flight tests on a modified Auster, illustrated in Figs. 8 and 9. They propose to investigate the effects of suction from the region of the wing leading edge, the flaps and the ailerons, and a small jet engine is installed to induce the suction quantities required. These tests should begin shortly. Meanwhile interesting investigations[33, 34, 35] have been made in the wind tunnel on the effects of suction on the turbulent boundary layer. The possibility of controlling the characteristics of the turbulent boundary layer by suitably modifying conditions at the surface has not been given serious consideration up to the present time, but I believe that this may prove a most fruitful field of research in the future.

8. Boundary Layer Drag and Heat Transfer at High Speeds

The theory of the two-dimensional laminar boundary layer in compressible flow is now well established and the transformations of Professor Howarth[36], Professor Stewartson[37] and Dr. Illingworth[38] have demonstrated that, subject to certain restrictions including zero heat transfer, a boundary layer problem in compressible flow can be solved by solving a related problem in incompressible flow. This result as well as a few exact calculations for cases involving heat transfer obtained with the aid of digital computers[39] has provided us with valuable test cases against which to assess simplified methods of solution involving some degree of approximation. One such method has been developed by Mr. Luxton[40], a research student in my Department, and he has demonstrated that with this relatively simple method he can predict the skin friction and other important characteristics of the boundary layer with good accuracy for a round or sharp nosed wing section with any surface temperature and with any prescribed pressure distribution.

Theories for the turbulent boundary layer are less well established. They involve the extension to high speeds of empirical relations that have been found reliable at low speeds, but for which the backing of experimental data covering adequate ranges of Mach number, pressure and temperature distributions has yet to be obtained. In a programme of work that Mr. Luxton has undertaken he has favoured a method developed by Dr. Spence[41] of the R.A.E. which we believe to be fairly reliable for Mach numbers at least up to about five and which has the merit of involving relatively little computing effort.

The results of Mr. Luxton's calculations show what appears at first sight to be a complicated dependence of frictional drag on Mach number, heat transfer and pressure distribution but a little thought has shown that these effects can be explained at least qualitatively in simple physical terms. Consider first the case of a flat plate with zero pressure gradient illustrated in Fig. 10. An increase of surface temperature, or an increase of Mach number with zero heat transfer, both result in a reduction of density near the surface due to the higher temperature there, a corresponding increase of viscosity and an associated change of velocity distribution. The effective changes of density and viscosity are equivalent to a decrease of free stream dynamic head and a decrease of Reynolds number, the former results in a corresponding reduction of skin friction while the latter increases it, but in smaller measure. However, when the boundary layer is laminar, associated changes in velocity distribution and therefore in rate of strain at the surface are quite marked and their effects on the skin friction are such as to nullify approximately the effects of the changes in density and viscosity. We find that the net effect on the skin friction is small, its magnitude and sign depending on the viscosity-temperature relation. For air it is a small decrease. With surface cooling or

FIGURE 8. Cambridge University research aircraft for investigating use of boundary layer suction for high lift.

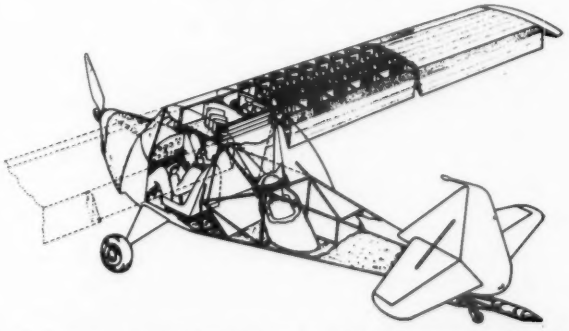

FIGURE 9. Cambridge University high lift research aircraft. Air can be sucked by jet engine in fuselage from forward parts of wings, from ailerons and from flaps.

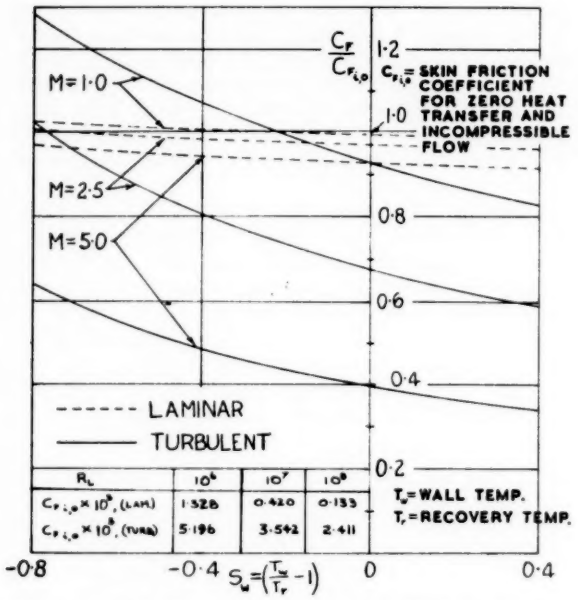

FIGURE 10. Skin friction on a flat plate with heat transfer, $\omega = 0{\cdot}89$, $\sigma = 0{\cdot}725$.

reduction of Mach number the skin friction is similarly increased. With a turbulent boundary layer, however, the velocity distribution is less sensitive to surface temperature changes and the associated effective Reynolds number changes are also less important. In consequence the net skin friction changes are dominated largely by the changes in effective density and hence we find a marked reduction of skin friction with increase of wall temperature and increase of Mach number and converse effects if the surface is cooled or the Mach number reduced.

If we now consider the effect of pressure gradient we can argue, as was first suggested by Dr. Illingworth[42] of Manchester University, that the decrease of density near the wall due to increase of surface temperature will result in a more ready response to the pressure gradient there in change of velocity and therefore in rate of strain and skin friction. Thus, a positive (adverse) pressure gradient would slow the fluid up more readily with the wall heated than with it cooled and would therefore augment the reduction of skin friction that would in any case occur with increase of wall temperature. Likewise a negative (favourable) pressure gradient tends to oppose the reduction of skin friction with increase of wall temperature and, if sufficiently powerful, may cause it to increase. Converse effects result if the wall is cooled. These effects are of major importance for the laminar boundary layer due to the sensitivity of its velocity profile to the influence of pressure gradient, but for the turbulent boundary layer where this sensitivity is much less these effects are generally of much smaller significance. In the latter case the direct density effects associated with changes of wall temperature tend to remain dominant. These points are illustrated in Figs. 11 to 14.

From a practical point of view we are most likely to be concerned with the effects of wall cooling combined with a favourable pressure gradient and we see that while this is likely to result in a small reduction of frictional drag with the boundary layer laminar there may be a considerable increase of frictional drag with a turbulent boundary layer. For example, Fig. 14 shows an increase of about 90 per cent due to cooling the wall to about one fifth of the stagnation temperature for a 5 per cent thick bi-convex wing at a Mach number of 5 with the boundary layer turbulent.

The full implications of these points need to be evaluated in more detail and the turbulent boundary layer theory used needs more experimental confirmation, but there may well be a strong case for boundary layer control at supersonic speeds with cooled surfaces, either to preserve laminar flow by suction or to reduce the skin friction with a turbulent boundary layer by blowing.

These results refer solely to two-dimensional boundary layers. A body of literature on three-dimensional boundary layers is growing up but the subject as a whole is still in its infancy. However, for the flow over slender wings at small incidences there are indications that the boundary layers behave effectively as in two-dimensional flow except in narrow regions close to the edges. This suggests that two-dimensional concepts will be of value for an important class of practical problems.

9. Hypersonic Flow

Above about a Mach number of 5 we enter the realm of hypersonic flow, a region of flow in which temperature rather than velocity changes occur with change of main stream Mach number, and the disturbances introduced by the forward part of a body in flight are confined to the relatively narrow region between the body and its nose shocks. For such flows the associated temperatures are generally such that the departure of the gas properties from those of an ideal gas become important. In readily realisable circumstances (*e.g.* the re-entry of a satellite into the earth's atmosphere) the temperatures behind the nose shock may be such that dissociation and ionisation of the gas occur.

Wind tunnels for providing conditions simulating such flows are extremely expensive and complex, but some of these conditions, albeit for an extremely short time, can be reproduced in a shock tube or in a test section after an expanding nozzle at the end of the tube. The relative simplicity of the shock tube is only in part offset by the elaborate electronic instruments required for accurate measurements in the small time intervals available, normally of the order of a few hundred micro-seconds. Thus we find that practically all University Aeronautical laboratories have in recent years been equipped with shock tubes. Much effort has had to be devoted to the development of suitable instruments and techniques for the measurement of flow properties, but now active programmes are well under way for the investigation of heat transfer, relaxation processes, shock attenuation and reflection processes. It is of interest to note that an ancestry can be traced for

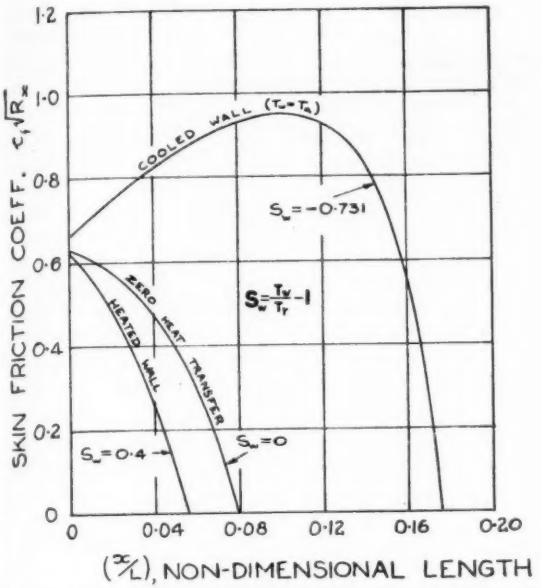

FIGURE 11. Influence of heat transfer on laminar skin friction with adverse pressure gradient. $u_1=u_a(1-x/L)$, $M_a=4{\cdot}0$, $\omega=0{\cdot}89$, $\sigma=0{\cdot}725$.

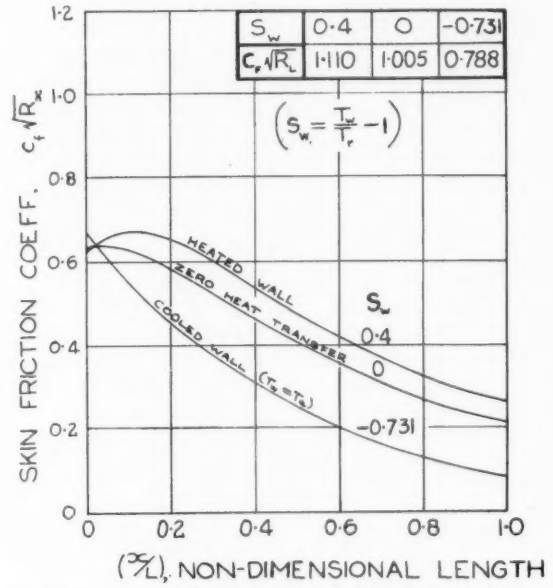

FIGURE 12. Influence of heat transfer on laminar skin friction with favourable pressure gradient. $M_1=M_a(1+x/L)$, $M_a=4{\cdot}0$, $\omega=0{\cdot}89$, $\sigma=0{\cdot}725$.

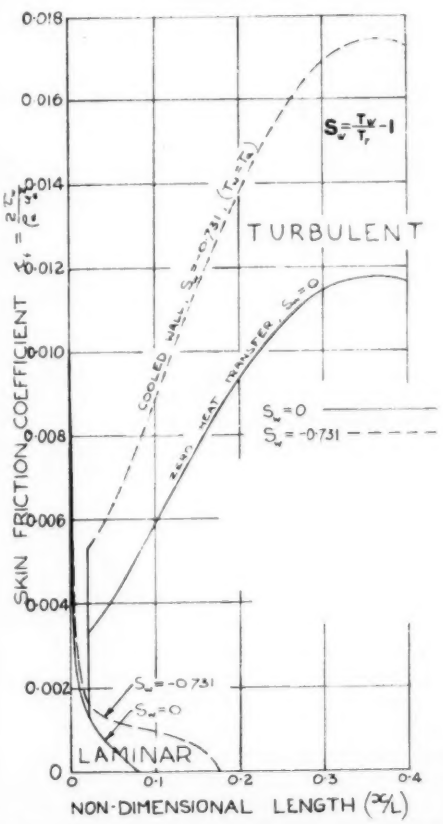

FIGURE 13. Effect of heat transfer on skin friction in an adverse pressure gradient. $u_1=u_a(1-x/L)$, $M_a=4{\cdot}0$, $\omega=0{\cdot}89$, $\sigma=0{\cdot}725$, $x_T/L=0{\cdot}02$, $R_L=10^7$.

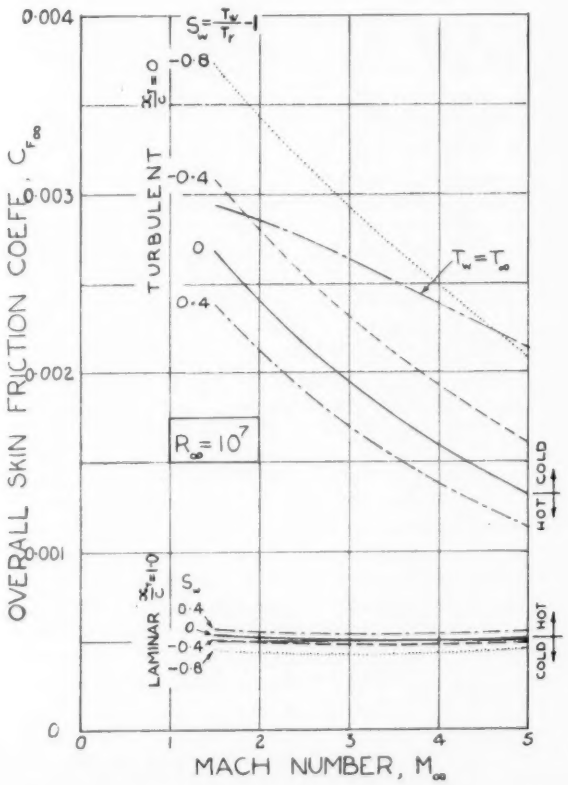

FIGURE 14. Skin friction on 5 per cent thick bi-convex wing—(one surface).

shock tubes back to the equipment devised by Professor Dixon of Owen's College, Manchester, in 1903 for an investigation of explosion processes.[43]

A related tool for the investigation of hypersonic flow problems is the gun tunnel. As with a shock tube a gun tunnel has a high pressure chamber and a low pressure chamber separated by a diaphragm, but there is also a free piston located at the diaphragm. When the diaphragm bursts the piston is driven down the tube and a shock wave forms ahead of it. This shock wave is reflected several times between the end of the tube and the piston before the latter is brought to rest and the gas between is strongly heated and compressed. The heated gas breaks a second diaphragm at the end of the tube and accelerates through a nozzle into a test section. The gun tunnel offers running times at least an order greater than do shock tubes because all the gas initially in the low pressure chamber is forced through the nozzle and working section. However, the duration of flow is still only a small fraction of a second so that the accurate measurement of flow properties remains far from easy. Both Southampton University and Imperial College are equipped with such tunnels and have already made some interesting investigations of their operation and of the measuring techniques required.[44, 45, 46]

Dissociation and recombination introduce additional difficulties in the theoretical analysis of hypersonic flow. Here, as in so many other problems of forbidding complexity, Professor Lighthill[47] has provided in a paper of first importance a theory of welcome simplicity and has thereby pioneered and inspired a valuable body of research work. In this paper he presented the concept of an ideal dissociating diatomic gas with relatively simple thermodynamic properties for a specified but wide range of temperature, based on acceptable approximations to the known behaviour of nitrogen and oxygen. He developed the analysis for the case of equilibrium flow when dissociation and recombination rates balance; later Dr. Freeman[48] of Manchester University extended the analysis to non-equilibrium flow. A serious lack at present is experimental information on dissociation and recombination rates, but experiments to meet this need are at present proceeding, or planned, at Imperial College, Southampton University and the College of Aeronautics, as well as at the R.A.E. and N.P.L.

10. Aeroelasticity

Aeroelasticity, the subject of Professor Collar's Lanchester Memorial Lecture[12], was once a no-man's land between aerodynamics and structures. That it is no longer a no-man's land but is actively cultivated by enthusiastic groups in the Industry and elsewhere is largely due to Professor Collar's vision and guidance. In his important paper to the Society in 1946[49] on the "Expanding Domain of Aeroelasticity" he first drew attention to the links that exist between the problems of stability and control, aeroelasticity and vibrations of aircraft and he suggested that with the aid of modern computers it should be possible to tackle quickly and effectively the equations governing all such problems for any particular aircraft as a single integrated process. As he subsequently remarked in his Lanchester Memorial Lecture[12], this dream has become a reality. The use of the automatic computer for problems of formidable numerical complexity has brought about a revolution in our outlook on such problems.

Towards the end of his Lanchester Memorial Lecture Professor Collar rightly remarked *a propos* aerodynamic derivatives for aeroelastic work that "we pine for what is not." I would like to strike a note of good cheer here, for in my Department as a result of the efforts of Dr. J. F. Clarke and Mr. B. M. Wood, as research students, we now have equipment for measuring derivatives in oscillatory motion of wings, bodies and wing-body combinations at low and high speeds. This equipment is on a modest scale, it is in a small high speed wind tunnel of working section 5 in. × 5½ in., but I believe that at present it is the only equipment in the country that will deal with a complete wing-body combination. Fig. 15 shows a block diagram of the essential components and a photograph of the equipment is shown in Fig. 16. The model is mounted on a sting and is driven in harmonic pitching oscillations by means of two swash plates acting through two push rods. The swash plates are in turn driven through gears by a Ward-Leonard variable speed drive. The axis of oscillation and the amplitude are set by adjusting the angles of the swash plates, and the phase of one swash plate can be adjusted relative to the other. The signal generated in a photo-cell by a light beam modulated by a cam on one swash plate shaft is amplified to supply a sinusoidal voltage to a bridge of four strain-gauges on the sting. The output from the bridge then has a mean d.c. level proportional to the component of the lift force or moment (depending on the bridge connections) in phase with the supply voltage. The photo-cell and lamp are mounted on a disc which can be rotated about the cam,

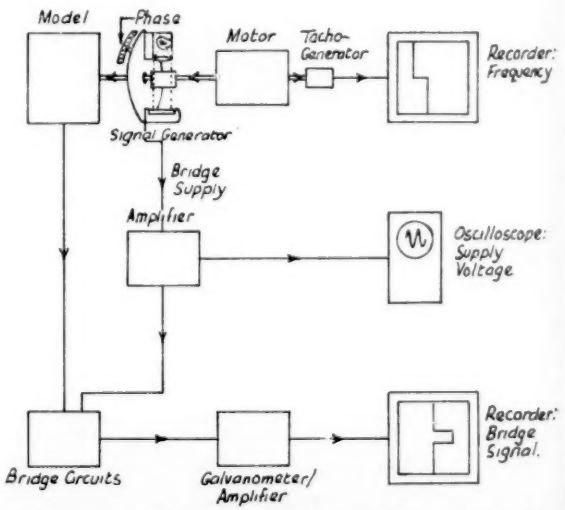

FIGURE 15. Oscillatory derivative apparatus: Queen Mary College.

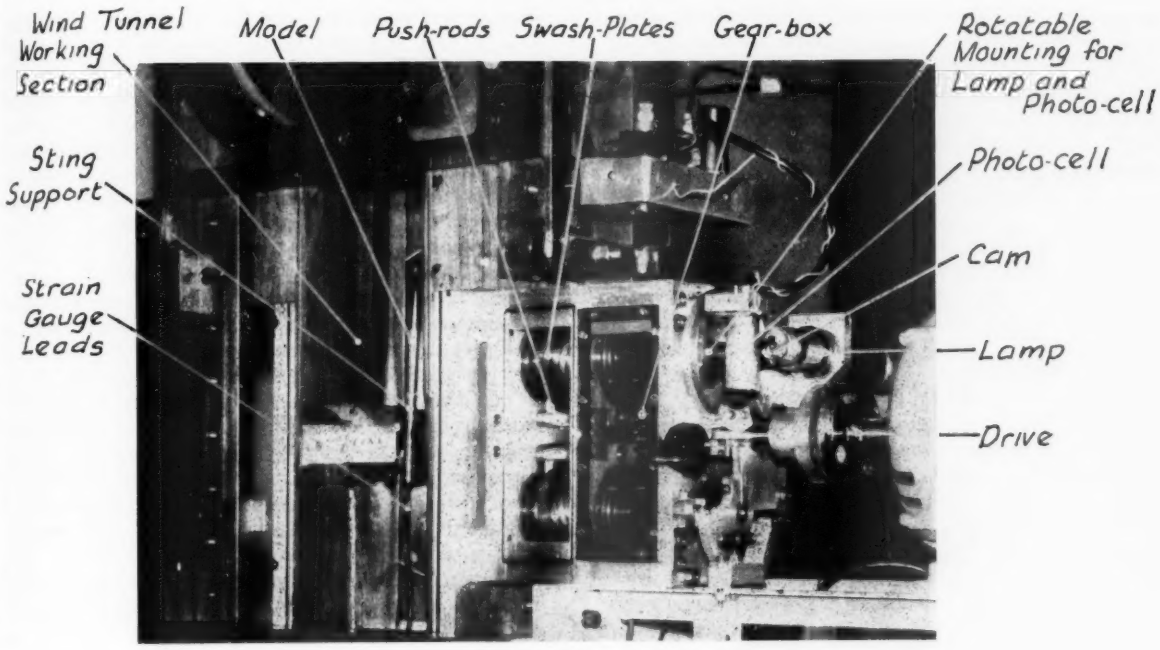

FIGURE 16. Oscillatory derivative apparatus: Queen Mary College.

altering the phase of the signal relative to the motion of the model and, with suitable phase settings, measurements of the stiffness and damping components of the force and moment can be obtained. The equipment is designed for frequencies up to 200 c./sec. A programme of work on various models of basic interest is at present in progress.

11. Structures

My previous reference to the growing use of digital computers in solving large scale aeroelastic and structural problems in aeronautics leads me naturally to the work of Professor Argyris[51, 52, 53] and his colleagues of Imperial College. His work is now widely recognised both here and abroad as of the first importance. The essential feature of this work is the consistent application of matrix methods, so logically suited to modern electronic computers, carried through from the initial data to the final formulation of the complete problem. The procedure has been reduced to one of remarkable simplicity, bearing in mind the essential complexity of the problems involved. Two dual techniques have been developed, the Matrix Force Method and the Matrix Displacement Method, the former uses forces and stresses as unknowns, and the latter uses displacements and strains. The former has advantages for investigations of fuselages and wings of moderate sweep and taper, while the latter is the more suitable for thin wings of high sweep or unconventional plan form. An interesting aspect of the method is that a structure involving cut-outs can be solved in terms of the solution for the basic structure without cut-outs and this process has been usefully generalised to permit the ready inclusion of structural modifications after the computations for the original structure of an aircraft are completed. The analysis allows for thermal stresses as well as those arising from external loads and dynamic effects. A parallel experimental programme is in progress in Professor Argyris's laboratory and the work is currently being extended to non-linear problems to take account of the influence of plasticity and creep.

Other important problems under investigation in his Department are the effects of kinetic heating on the torsional and flexural stiffnesses of thin wings[54], including the cross-coupling that can occur between these two effects when the displacements are large, and stiffness and stability problems of sandwich panels.

Structural damping is another major topic that has attracted the attention of University workers, in particular at University College,[55] Southampton University,[56-59] Bristol University and my own Department.[60, 61] The earliest work on damping in solid materials in steady periodic motion indicated that the damping forces were sensibly independent of the frequency and proportional to the amplitude. This has formed the basis of a linear theory of structural damping based on the concept of a complex stiffness which has been developed in some detail by Professor Bishop of University College. It must be noted, however, that there is as yet no experimental justification for the extension of this theory to transient motions, where one might expect the previous history of the motion to be of significance.

Work on built-up structures has generally revealed some non-linearity even at small amplitudes, although the damping was still independent of frequency. Thus, experiments by Mead of Southampton University on

beams with riveted joints show an energy loss per cycle proportional to the amplitude to the power 2·7. It would seem that the most probable cause of damping in both solid and jointed structures is hysteresis. Milne[60] of my Department has therefore developed a non-linear theory for the periodic motion of continuous systems based on a general form of the stress-strain relation which may be double-valued and in his theory joints are represented as small regions of the structure which have prescribed force-displacement characteristics.

We must also note the interesting investigations of Mead into the use of damping compounds such as Aquaplas to reduce the amplitude of vibrations, such as those caused by noise, with a view to reducing the possibility of fatigue.

As Professor Collar[12] and others have pointed out, the effect of structural damping on flutter is by no means simple, for while the damping forces increase dissipation and to that extent may reduce the possibility of flutter, they may so alter the modes of motion for this direct effect to be swamped by consequent and adverse changes in the energy input which reduce the flutter speed.

This topic is clearly one to which we may expect the Universities to continue to make useful contributions.

12. Engine Problems

Inevitably financial and space limitations have restricted University departments concerned with engine research almost entirely to the problems that could properly be regarded under the heading of internal aerodynamics. Thus, the flow in pipes and ducts, diffusers, bends, cascades, turbine and compressor stages and the associated secondary patterns of flow have figured largely in the research programmes at Cambridge, Imperial College and Liverpool.

At Cambridge Professor Hawthorne[62, 63, 64] and his colleagues have devoted a great deal of attention to the subject of secondary flows in bends, and important contributions to this topic have also been made by Professor Squire[65] and Professor Preston[66]. As a result we have a valuable physical picture of how secondary flows develop due to the way in which vorticity, which upstream of a bend may be normal to the flow direction, acquires a component in the streamwise direction as the flow turns the bend. It is this streamwise component of vorticity which is associated with the secondary flow field. Inviscid flow theories have been developed leading to useful expressions for this secondary flow in terms of the upstream vorticity and the angle of the bend. When applied to the flow in a curved pipe the analysis shows the secondary flow to be periodic with distance along the pipe axis, and this interesting result is in good accord with experiments by Squire[67] and by Miss Percival[64] at Cambridge. Miss Percival's experiments also show that the losses in the curved pipe and any subsequent straight lengths of pipe depend to some extent on the phase of the secondary flow at the end of the curved pipe, and this implies that the losses involved in any ducting system cannot always be reliably predicted by treating the separate components as independent. Further advances in the theory of secondary flows will require more effective consideration of the effects of viscosity, the problems are then three-dimensional boundary layer problems of some complexity. There is already evidence that current work on three-dimensional boundary layers will have many fruitful applications to the subject of secondary flow.

The practical importance of these secondary flows in cascades, compressor stages and turbines lies in their tendency to sweep the boundary layers into corner regions of local low pressure, and these accumulations of " tired " air when faced with subsequent adverse pressure gradients are liable to separate, with consequent energy losses and reduction of efficiency. Experiments have been made at Cambridge[64] and Imperial College to investigate the effects of boundary layer suction as well as spanwise variations of blade section, camber and twist on secondary flows. These tests indicate that important changes to the secondary flow and the consequent losses can be made by such means, but more work remains to be done before their full practical implications can be properly assessed.

Another important problem to which attention has been directed at Universities is that of the propagating or rotating stall found under certain conditions in the stages of an axial compressor. Theoretical analyses, based on the crude approximation of regarding the stalled flow as a small perturbation on two-dimensional potential flow, have succeeded in demonstrating the main features of the mode of propagation of the stall.[68, 69] An equally successful theory due to Dr. Whitehead of Cambridge treats the compressor stage as an actuator disc subjected to a small harmonic disturbance.[70] Dr. Louis, also of Cambridge, has considered a different type of propagating stall which is met only in rotor stages.[71] According to his theory " dead " air from the rotor hub, which is initially stalled, moves rapidly outwards under the action of centrifugal forces to extend the stalled region. This causes blockage of the channel at high incidences and the channel then acts like that of a centrifugal compressor delivering reversed flow at the tip. The stall cell thus acts as a sector of a centrifugal compressor moving at its own speed behind the rotating blade row. Louis infers that the essential criterion for the development of this type of stall and its speed of propagation is that the total head produced by it at the tip is higher than that at the unstalled tip. Experiments at Cambridge and elsewhere show good agreement with the predicted speed of propagation.

The problem of the rotating stall is just one of the many problems involved in the general subject of the vibrational characteristics of sets of rotating surfaces generating aerodynamic forces. Although specifically directed to the problem of the helicopter, the work of Dr. Jones[72] of Southampton is very relevant in this connection, since he has demonstrated the importance in certain circumstances of the coupling effects between the cast-off vortices from one blade on the oscillations of a succeeding blade.

Finally I come to a topic of considerable and growing importance for which the basic research in this country

has been almost exclusively the work of the Universities, albeit sponsored very largely by the Ministry of Aviation. I refer to the topic of jet noise. Over a number of years considerable effort has been devoted to this subject by Professor Richards and his colleagues at Southampton,[73-77] by Mr. Lilley and his colleagues at the College of Aeronautics[78-80] and by Professor Lighthill and his colleagues at Manchester.[81-83] To Professor Lighthill[81] we owe yet another great debt for his now classical theory of aerodynamic noise in which he demonstrated that the basic noise generators in a jet exhaust were quadrupoles of strength related to the turbulence and shear. He developed formulae for the noise intensity and demonstrated the strong directional effect of the noise field. The workers at Cranfield and Southampton have provided us with a large body of experimental data on the near and far noise fields, and such success as has attended our current efforts at noise suppression is due in large measure to the early results obtained at Cranfield. Valuable work has also been done on the development of ground mufflers. Now attention is being directed to the near field and its effect on neighbouring structures and to boundary layer noise. At Southampton a considerable amount of effort is being devoted to the measurement of correlations in space and time of turbulence and pressure fluctuations in and close to a jet. This work promises to be most fruitful in improving our understanding of the detailed structure of the jet noise field and of the response of the aircraft structure to the associated fluctuating pressure field.

It is a widely expressed view that no further significant reductions in jet noise can be expected from suppressors. My feeling is that this view is unduly pessimistic and much useful research remains to be done on noise suppressors. However, I do not believe that suppressors can ever provide more than a partial, if welcome, alleviation and I agree with the general view that engine designers must treat this problem of noise as of first importance from the earliest design stages. From this point of view, as well as others, by-pass engines appear to be a step in the right direction.

13. Concluding Remarks

The pattern of fundamental research in aeronautics in this country is a closely woven one, with the Government research establishments, the Universities and the Industry all contributing to it. I must confess that it has not been easy to separate the threads of University work from the others in this pattern and if indeed in this hurried survey I have inadvertently given the impression by default that the fundamental research done other than at the Universities is not of first importance then I must hasten to correct that impression, for nothing could be further from the truth. Nevertheless, the Universities have always had a distinctive and vital part to play and this, I think, derives largely from their tradition of academic independence, a tradition which is perhaps stronger here than in any other country. Thus it has always been possible for University staff to follow any line of interest that they wish, within the limits of their resources, free from the pressure of current urgencies and official priorities. However well equipped and well organised the official establishments may be, we cannot afford to be without some independent centres of research with this kind of freedom. Nevertheless, were the academic freedom of the Universities to remain unaccompanied by the stimulus of close contact with the Government establishments and with industry, it could readily result in a state of sterility. Therefore as a complement to this academic freedom we must have the closest co-operation between all the bodies concerned with aeronautical research. That we have in fact achieved a high degree of co-operation is due in large measure to the Aeronautical Research Council. A cynic once remarked that a camel is a horse designed by a Committee. There is an element of truth in this but, like the camel, Committees have their terrain in which they are pre-eminently useful. Even if it is not the Council's primary purpose an important by-product of its activities is the co-ordination of the country's research effort on a voluntary basis that results from the way the Council and its Committees regularly bring together research workers of like interests from the Government establishments, the Industry and the Universities. This Society through its lectures and technical committees has also played an important part in the co-ordination of research effort.

Can more be done by way of interchange of staff to make the contact between these bodies even closer? On this point I must note that such interchange seems to be much more difficult in this country than in other countries. I am not sure why this should be so, and I think that this question of interchange would repay a great deal of thought and energy being given to it. I am well aware of the excellent scheme whereby members of University staffs are encouraged to work at Government establishments for short periods as Vacation Consultants, but I would like to see such arrangements extended occasionally for longer periods and made reciprocal so that exchanges for complete academic sessions or even longer can take place. Such reciprocal arrangements could well include staff from the firms. Government scientists have on occasions been seconded to American Universities for a year or so; this is an excellent idea but it would be no less valuable to all concerned if secondments could also be made to British Universities.

I have already referred to the slender financial resources of University Departments and to the fact that most Departments welcome the extra financial support obtained by undertaking research contracts with the Ministry and other agencies. However, such contracts represent some loss of independence, although the red tape involved has been reduced by the understanding officials concerned to a surprising minimum. Hence there is clearly a limit to the number and value of contract commitments a University Department can safely undertake. We seek such contracts in the main to pay for junior research staff and the situation would be eased a great deal if the University Grants Committee could find it possible to provide Universities and Colleges more generously than at present with funds out

of which appointments to research Fellowships and Assistantships could be made. There are few Colleges that are able to include on their staff posts of this nature, and then only when they are lucky to obtain endowments for this purpose from Industry and elsewhere. In this connection I would like to suggest to Industry that such endowments are excellent investments and might be spread to advantage more thickly and evenly over more Universities and Colleges than at present. I hope that this survey will have made it clear that good work is being done in many more places than those that normally figure in bequests and endowments.

What of the future? Certainly the possible lines of development have never been so numerous or so ambitious as at present, ranging as I have already noted from V.T.O.L. to hypersonic transport aircraft and even space travel. However, it would seem that the research problems associated with these developments may well call for vast resources in money, man power and equipment, far beyond the capacity of any University Department. Can we then expect the Universities to continue to make a vital contribution to the research effort of the country? In my view we can be optimistic on this score. Certainly an increasing range of problems will call for resources on a scale that only the Government establishments can deploy, but I think that these problems will not necessarily include all or even the majority of the fundamental problems, and in the solution of many of the latter the Universities should continue to play a major part. For such problems a limitation of resources can sometimes be a stimulus rather than a hindrance, just as large expensive equipment can sometimes dominate rather than serve the people responsible for it. The history of aeronautical research like that of any other science and technology shows clearly that it is men that matter rather more than resources. For an outstanding example we need not look farther than the man whose memory we are here to honour tonight. Dr. Lanchester's resources were very modest by any standards but by virtue of his remarkable capacity for grasping the physical processes involved in any problem in which he was interested, he was able to make advances of fundamental importance in a wide range of subjects.

I conclude therefore that as long as the Universities retain their strong sense of independence, as long as everything is done to maintain a close contact between them, the Government establishments and the Industry, and as long as the Universities maintain the scientific tradition and insight that is exemplified in the work of such men as Dr. Lanchester, so long will their contributions to aeronautics remain of vital importance.

ACKNOWLEDGMENTS AND APOLOGIES

I am most grateful to my many colleagues and friends in various Universities and Colleges, too numerous to be named separately here, who have provided me with valuable assistance and advice and with much of the data on which this Lecture has been based. I am acutely conscious of the vast range of topics and activities of first importance to which I have not found the time and space to make any reference. The Department of Scientific and Industrial Research issue each year a sizeable book called "Scientific Research in British Universities," which provides a complete list of topics, and reference to this book will show what a remarkable proportion of the research activities stem directly or indirectly from aeronautical engineering. To those responsible for those important activities that I have omitted to mention I must apologise for the personal bias that has conditioned the selection that I have made; I can only hope that the bias has not invalidated the general picture presented in the Lecture.

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Dr. Moult: As might have been expected from one of the leading members of the teaching profession they had had a very complete and lucid lecture in which they had learnt how important a part the British Universities had played, and were still playing, in aeronautical research. Altogether this was a very impressive account of which, nationally, they could be proud. The fact that much of this work had been done on a shoe-string was, no doubt, an achievement, but he did not think the principle was one on which they could afford to depend in this highly competitive world. They were all most indebted to Professor Young for his lecture and he would ask Dr. Cawood, Member of Council, to propose the Vote of Thanks.

Dr. Cawood: He was sure that they had all enjoyed Professor Young's discourse and it gave him the greatest pleasure to say so because he knew him and his work so well.

This was the fourth of the lectures commemorating Dr. F. W. Lanchester and to him it was the most important of their commemorative lectures because it commemorated a British pioneer in the science of aeronautics. Professor Young had maintained the standard set by his predecessors. He had given them a glimpse of the valuable and fundamental work which had been undertaken by the universities in the past few years and he had mentioned many familiar names. He was rather surprised when Professor Young said that he felt there should be more exchange between the Government Service and the Universities because nearly all of these names were men who had been his colleagues in the Service during the past few years and, on the basis of probabilities, the few exceptions would probably join them in the next few!

He always thought that engineering research of any kind in universities had presented a difficult problem because of the scale and cost of the equipment involved. Aeronautics used to head the list in this respect although he supposed that nuclear research now might have pride of place. He knew, when in 1939 he left the string and sealing wax of his university laboratory, he was quite appalled and extremely frightened by the sophistication of the wind tunnels, structures frames and the engine test beds at Farnborough and he really did not think that this could be right and that this sort of sophistication was necessary for true research; but later he joined the staff of the R.A.E. and became acclimatised to this outlook. Possibly he had swung too much the other way after a few years at the R.A.E. and wondered whether there really was a place for the universities in aeronautical research apart from the more theoretical attacks.

Professor Young had left them in no doubt of the vital and fundamental part which the universities would always play in aeronautics and he thanked him for presenting it to them in such a palatable form. Nevertheless, he thought that when Professor Young stressed the slender financial resources available to the universities that he had had one eye on the Secretary of the Department of Scientific and Industrial Research and the other on the Chief Scientist of the Ministry of Aviation. Professor Young began his lecture with a quotation of Lanchester's supporting university research and he was very happy to see that the scholastic establishments had reciprocated—there was at Southampton University a Lanchester Hall in the Engineering Department, at Coventry there was a Lanchester College of Technology and the College of Aeronautics had a Lanchester Hall and, there was this lecture.

In conclusion he would quote two rather moving and pathetic lines from a poem written by Lanchester himself:—

"His soul was in his work which living on bears fruit
So doth a soul attain immortality."

Following the Lecture a Dinner was held at 4 Hamilton Place, London, W.1, at which the following were present:—

Dr. A. M. Ballantyne, T.D., B.Sc., Ph.D., F.R.Ae.S., Hon.F.C.A.I., F.I.A.S., Secretary, Royal Aeronautical Society; A. D. Baxter, M.Eng., F.R.Ae.S., M.I.Mech.E., Member of Council, Royal Aeronautical Society; Professor J. A. J. Bennett, D.Sc., Ph.D., F.R.Ae.S., Member of Council, Royal Aeronautical Society; E. C. Bowyer, C.B.E., Director and Chief Executive, S.B.A.C. Ltd.: Major G. P. Bulman, C.B.E., B.Sc., F.R.Ae.S., Honorary Treasurer, Royal Aeronautical Society.

Dr. W. Cawood, C.B., C.B.E., B.Sc., F.R.Ae.S., Sir Robert Cockburn, C.B., O.B.E., M.Sc., Ph.D., A.F.R.Ae.S., Members of Council, Royal Aeronautical Society.

Sir George Edwards, C.B.E., B.Sc., Hon.F.R.Ae.S., Hon.F.I.A.S., Past-President, Royal Aeronautical Society.

Sir William S. Farren, C.B., M.B.E., M.A., D.Sc., F.R.S., Hon.F.R.Ae.S., Past-President, L. G. Frise, B.Sc., F.R.Ae.S., A.F.I.A.S., Member of Council, Royal Aeronautical Society.

R. W. G. Gandy, M.A., B.Sc., A.F.R.Ae.S., Secretary, Aeronautical Research Council; Sir George Gardner, K.B.E., C.B., D.Sc., F.R.Ae.S., M.I.Mech.E., Member of Council, Royal Aeronautical Society; H. H. Gardner, B.Sc., F.R.Ae.S., Member of Council, Royal Aeronautical Society; Robert Graham, C.B.E., F.R.Ae.S., M.I.Mech.E., Director, Microcell Ltd.

Dr. G. V. Lachmann, F.R.Ae.S., Research Director, Handley Page Ltd.; Mr. George Lanchester, Brother of the Late Mr. F. W. Lanchester; M. J. Lighthill, F.R.S., Director, R.A.E.

Sir Hamish MacLaren, K.B.E., C.B., D.F.C., LL.B., B.F.C., President, Institution of Electrical Engineers; Professor W. A. Mair, M.A., F.R.Ae.S., A.F.I.A.S., Francis Mond Professor of Aeronautical Engineering, Cambridge University; P. G. Masefield, M.A., F.R.Ae.S., Hon.F.I.A.S., M.Inst.T., Immediate Past-President, Royal Aeronautical Society; Sir Harry Melville, K.C.B., F.R.S., Secretary, Department of Scientific and Industrial Research; M. B. Morgan, C.B., M.A., F.R.Ae.S., Member of Council, Royal Aeronautical Society; Dr. E. S. Moult, C.B.E., B.Sc., F.R.Ae.S., M.I.Mech.E., President, Royal Aeronautical Society; Professor A. J. Murphy, M.Sc., F.I.M., F.R.Ae.S., Principal, College of Aeronautics, Cranfield.

F. M. Owner, C.B.E., M.Sc., F.R.Ae.S., Consultant, de Havilland Engine Co.

Colonel R. L. Preston, C.B.E., A.F.R.Ae.S., Secretary General, Royal Aero Club; Captain J. L. Pritchard, C.B.E., Hon.F.R.Ae.S., Hon.F.I.A.S., Secretary, Royal Aeronautical Society, 1925/1951; Sir Alfred Pugsley, O.B.E., F.R.S., F.R.Ae.S., Professor of Civil Engineering, Bristol University.

Professor S. C. Redshaw, F.R.Ae.S., Professor of Civil Engineering, Birmingham University; Professor E. J. Richards, M.A., B.Sc., F.R.Ae.S. Professor of Aeronautical Engineering, Southampton University.

B. S. Shenstone, M.A.Sc., F.R.Ae.S., F.C.A.I., A.F.I.A.S., Vice-President, Royal Aeronautical Society; Sir Richard V. Southwell, M.A., Hon.F.R.Ae.S., Hon.F.I.A.S., Hon.M.I.Mech.E.; Air Marshal Sir Herbert D. Spreckley, K.B.E., C.B., F.R.Ae.S., M.I.Mech.E., Member of Council, Royal Aeronautical Society.

Dr. A. P. Thurston, M.B.E., D.Sc., F.R.Ae.S., M.I.Mech.E., F.C.I.P.A., Consultant.

L. A. Wingfield, M.C., D.F.C., A.R.Ae.S., Solicitor, Royal Aeronautical Society; T. A. Wolstenholme, A.R.Ae.S., Member of Council, Royal Aeronautical Society.

Professor A. D. Young, M.A., F.R.Ae.S., A.F.I.A.S., 1960 Lanchester Memorial Lecturer.

Ballistic Research Rockets With Particular Reference to Black Knight

BY

D. J. LYONS, B.Sc.

(Senior Superintendent, Ballistic Missile Group, Royal Aircraft Establishment)

The 1172nd Main Lecture to be given before the Society and the 41st to be held at a Branch centre " Ballistic Research Rockets with Particular Reference to Black Knight " was given under the auspices of the Luton Branch on 1st December 1960. Mr. F. H. Pollicutt, F.R.Ae.S., Chairman of the Luton Branch opened the meeting by welcoming the President, Dr. E. S. Moult, C.B.E., B.Sc., F.R.Ae.S., M.I.Mech.E., the other members of the Council of the Main Society who were present, and representatives from the Bristol, Birmingham and Wolverhampton, Coventry, Christchurch, Derby, Hatfield, Halton, Henlow, Preston and Weybridge Branches. He then asked Dr. Moult to preside over the rest of the proceedings.

Dr. Moult expressed his pleasure at being present on this occasion—the second time a Main Society Lecture had been presented at the Luton Branch—and then introduced the Lecturer, Mr. D. J. Lyons. Mr. Lyons took his degree in Aeronautical Engineering at Queen Mary College and subsequently joined the Wind Tunnel staff at Farnborough. During the war he became a flying instructor in the R.A.F. and later rejoined the Aerodynamics Flight Section at the R.A.E. For the next ten years Mr. Lyons was engaged in Flight Research on stability and control. In 1951 he was appointed Superintendent of the Experimental Projects Division in the Guided Weapons Department and in 1955 was promoted to his present position as Senior Superintendent of the Ballistic Missile Group of the Guided Weapons Department. He had been responsible from the Ministry aspect for the research and development connected with the Black Knight and Blue Streak Missile systems.

1. The Role of the Research Rocket

The ballistic rocket can be defined loosely as a rocket which for the most part of its trajectory is unpowered and unguided, its course having been dictated by its velocity and position at motor cut-off. Although there is a gradual transition, with many branches, from the air-supported missiles to satellite launching vehicles, I will confine myself to the research aspects of the types of true ballistic rockets which spend all or the greater part of their ballistic trajectory out of the thicker atmosphere.

Now the main research tasks on ballistic rockets fall into two groups, first those associated with the problems of design of such rockets in all its aspects including guidance, launching and re-entry into the atmosphere, and secondly, those associated with the measurement of environment, particularly that of little explored upper regions of the atmosphere and of space.

2. Types of Vehicle for Environmental Measurement

Some types of environmental measurement depend on, or are improved by, spending a very long time, hours or days, at or above a given altitude. This requirement can only be met by satellite vehicles which will not be considered further here.

A vertically launched rocket will, however, depending on its cut-off speed, spend a certain time above a given level. Fig. 1 shows the time spent above 40 n. miles altitude as a function of cut-off speed and maximum altitude reached; the height of cut-off having been varied in an approximate but realistic manner as performance is improved. For quite a number of simple or even complicated environmental measurements these times have proved to be sufficient, in fact for many only a very short duration at a desired altitude will suffice.

In choosing a vertical sounder which will be satisfactory for such experiments the main factors which have to be considered are usually: —

(*i*) the maximum height to be reached,
(*ii*) the instrumental payload to be carried,
(*iii*) whether contamination from the outgassing from the rocket is important,
(*iv*) whether any form of stabilisation is required, *e.g.* whether any particular sensor has to be pointed at or away from the sun or the earth.

These last two considerations have to receive special consideration whatever the launching rocket and do not usually affect the choice. All rockets contaminate the surrounding space even after they have stopped thrusting, from the gases escaping from the spent solid motor or hot combustion chambers of the liquid motor, from the pressurised instrument spaces and tanks and from

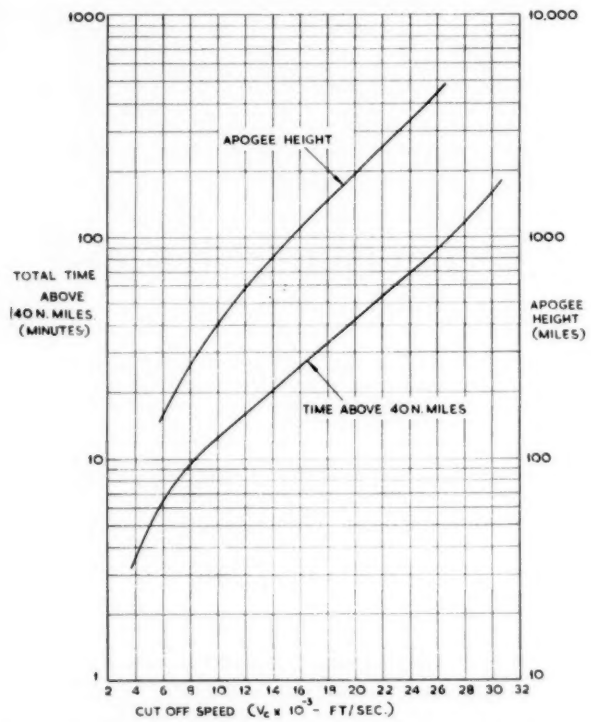


FIGURE 1. Total time above 40 n. miles and apogee height as a function of cut-off velocity.

the pores of the rocket structure itself. For experiments which depend on an uncontaminated atmosphere, there is usually only one recourse, the experiments' sensor at the least must be separated from the main rocket in a structure on which special sealing precautions have been taken, including sealing of the skins; information can be passed down a cable back to the main rocket or instrument compartment. This system has been effectively used by Boyd in a Skylark rocket. Appreciable reduction in contamination can be obtained, however, by shielding sensors from direct outgassing from trouble spots such as rocket venturis.

If stabilisation is required, this has to be provided separately on the payload capsule by itself after separation, which is the most efficient, or on the whole rocket which is sometimes the simplest solution.

Turning back to the performance aspects, the weight of the instrumentation and battery power supplies for individual environmental experiments is often very small. Typical figures vary between ½ lb. and 8 lb. for a large number of different experiments undertaken on Skylark and Black Knight, but the weight of the telemetry sender and its power supplies used to transmit the information gathered back to the ground or of a magnetic tape recorder and its supplies is often much greater (typical installations in Skylark and Black Knight weigh 15–20 lb.). It is common, therefore, to find a number of experiments of quite different character being done on one flight in order to reduce the "overheads." Naturally, there are always special experiments,

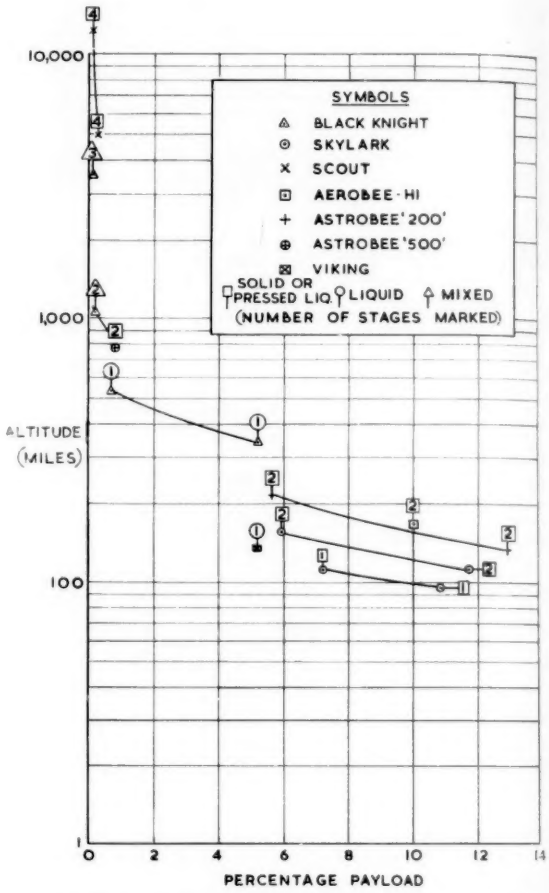


FIGURE 2. Performance of a number of ballistic research rockets.

such as the well known grenade or sodium cloud experiments, which will swallow up large payloads of the order of 100–200 lb. and greater.

Of course, the greater the height at which the experiment must be made or the greater the time that must be spent at altitude (to allow a very long aerial to be wound out for instance), the more complex the vehicle becomes. So when great altitudes are to be reached, there is a still greater economy to be found in combining experiments in one round; for instance, we have treated our space-environmental instrumentation carried on Black Knight as a kind of supercargo, while much more ambitious main ballistic rocket experiments have been in progress. For low altitudes, say up to 100 n. miles which can be reached by a relatively unsophisticated rocket, the economic payload can be much lower.

A good and well known figure of merit in judging the efficiency of a rocket is the payload expressed as a percentage of the all-up weight of the vehicle at take-off, for a given trajectory. I have plotted in Fig. 2 the percentage payloads for a number of well known research rockets, all being fired vertically, and I have used the maximum altitude gained and the cut-off speed

as an arbiter of the performance. (American information is obtained from Newell's book *Sounding Rockets**.) I have marked the single-stage, two-stage, and so on, and liquid and solid rockets in different ways. Although such a plot contains a large number of hidden complicating parameters due to the individual rocket designs, two main observations can be made, which are supportable by specific performance estimates, these are:—

(*a*) That the efficiency in terms of payload carried is immensely lowered as maximum altitude is increased.

(*b*) That an appreciable improvement in performance is obtained with pump-fed liquid rockets in comparison with solid rockets, despite comparable Specific Impulse figures being obtained for the basic propellant. The balance can only be redressed by adding an extra stage to the solid rockets. Liquid-fuelled rockets which are fed from pressurised tanks have few performance advantages over solid rockets as they need very strong and heavy tanks similar to solid rocket bodies in order to withstand the high pressure, and the weight of these is one of the main reasons for the lower performance of these and solid rockets.

Figure 3 shows outlines of the rockets given as examples in Fig. 2.

In making a choice between the various types of rocket for measurements of the space environment, maximum performance for a single stage is not, however, the only criterion. For maximum altitudes of the order of 100 miles or so the simple solid rockets such as Skylark have many attractions, especially as spin stabilisation or a long launcher (as is used in Skylark) can bring the dispersion down to a reasonable figure without having to put in the complexity of a control and guidance system. As maximum altitude is increased, however, and the need for a control system to reduce dispersion is introduced, the choice tends to favour the liquid rocket such as Black Knight which, besides being of higher performance, is somewhat easier to control. One cannot pretend, however, that the choice is a simple one and not open to doubt, for it can be argued that the staging of solid rockets is a well understood and an easily engineered solution, that they can be made roughly equivalent in performance to liquid pump-fed rockets by the addition of one extra stage, and that the control problems, although perhaps more severe, do have practical solutions.

Although arguments will go on as to the merits in performance efficiency, simplicity, development cost, production cost and so on, the experimenter interested in upper air exploration will not particularly care what kind of missile carries his measuring apparatus to the heights required and, for the more highly performing and expensive vehicles, the choice will often mainly be determined by what vehicles are available from other uses.

*McGraw-Hill, New York, 1959.

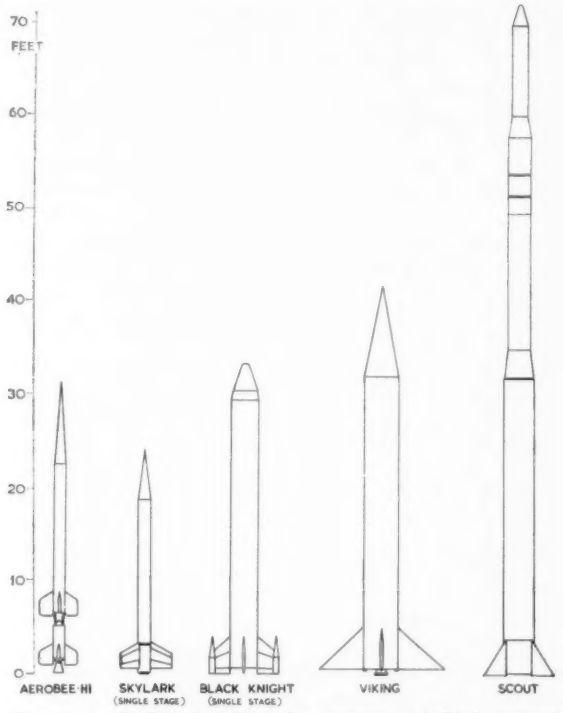


FIGURE 3. Outline drawings of a number of ballistic research rockets.

3. Research into the Design of Ballistic Rockets

The first and most obvious observation to make in considering types of ballistic research rockets for vehicle research, is that the initial design of research rocket can be critically influenced by the types of ballistic rocket for which the research is being done. If the end-products are known to be liquid-fuelled rockets, then this will predispose one's choice for the research rocket towards liquid; if the end product were to be an air-launched solid rocket then one tends to produce a research rocket of similar character so that the main problems are encountered. Of course, the practical situation is more complicated than this, in that usually one can see the first end product but not necessarily the subsequent ones, and these may well be in a different class. Fortunately, however, although some of the Research and Development problems are critically different in the different classes of ballistic rocket, many problems are identical or of similar nature. The research on one type of rocket, besides gaining us experience and giving confirmation or modification of calculations and/or experiments made on ground facilities, will also give a certain amount of basic information relevant to the special problems of other classes of ballistic rocket, so that added realism can be introduced and extra confidence can be gained from ground experiments concerned with the particular problems of these classes.

Furthermore, for a particular class of ballistic rocket, say a liquid-propelled, multi-stage missile, the main

research problems do not vary greatly with the intended use of the end product, *e.g.* a ballistic deterrent rocket and a scientific satellite launcher present basically similar design problems.

Thus a single research rocket of a specific type can cover a wide range of common problems and can be adapted to gain information on some of the special problems of other classes of ballistic rocket. The choice of type to be used is likely to be a matter of expediency, availability or related to the immediate project development, but there may well be no compelling need to charge completely the research vehicle as one moves to, or considers, ballistic rocket projects in other classes.

Many of the design problems can be largely resolved by ground tests; the propulsion system can be run and tested for reliability, the aerodynamics of the boost can largely be exposed by wind tunnel tests, the structure can be tested for the various loads expected, even though increased complexity is introduced by the high degree of kinetic heating, and so on. But there still remain important areas, which because of the complexity of the interactions involved or because of the doubtfulness of the assumptions, still need the exploration which only a flight test can offer, before one could with certainty undertake a full project development. We must also not forget that the flight test may and does reveal problems we had not even thought about or had misunderstood.

In Fig. 4, I have put down the main problem areas which need flight investigation and I have separated those for liquid rockets from those for solid rockets to show the equivalence to which I have referred. Two of these areas which are common to solid and liquid rockets, the base heating and the collision between payloads and boost after separation, are problems that we only half-understood before flight tests began. The list is not meant to be comprehensive, but is illustrative of the problems to be investigated by a research rocket —some of them will be dealt with in more detail later.

In this country the design of ballistic research rockets was not started until 1955 and the Blue Streak rocket naturally influenced our design considerations which led up to the Black Knight rocket. We did, however, consider first, both a wide range of multi-stage solid designs and also many variations in both the engines and the design parameters of the Black Knight rocket itself. The main criteria that we used in choosing the particular design for the Black Knight were that: —

(*a*) it should be of very high performance both in its single and two-stage versions, so that the problems of obtaining high performance such as the necessity for light structure weights would be encountered, and so that exit and re-entry conditions were in the range that we were likely to encounter in our future project design,

(*b*) the payload should be reasonably high, of the order of 150–300 lb., so that complicated and comprehensive instrumentation could be used. Provision for special payloads up to 600–800 lb. was also required,

Main topic	*Liquid propelled*	*Solid*
PROPULSION	Propellant utilisation.	Prevention of undue sliver remaining.
	Thrust dribble after cut off.	Erratic sliver burning.
	Base heating from expanding gases.	As for liquid.
STRUCTURE	Kinetic heating on structure.	Kinetic heating on structure and charge.
	Bounce on launcher during static firing.	———
	Design against vibrational environment.	Design against rather more severe vibrational environment.
CONTROL	Effect of structural flexibility on control stability.	As for liquid.
	Fuel sloshing.	———
	———	Provision of satisfactory jet deflection.
	Effect of aerodynamics on control.	As for liquid.
SEPARATION	Light up of 2nd and further stages.	———
	Avoidance of collision between stages and payload after separation.	As for liquid although usually not as severe in the case of stage separation.
MISSILE GUIDANCE RE-ENTRY into the atmosphere. COMMUNICATIONS to and from the rocket.	Similar problems in all classes.	

FIGURE 4. The main research areas in flight.

(*c*) the rocket should be controlled and guided so that the problem areas here were exposed,

(*d*) short development time was highly desirable as our entry into the field was late, and there was a compulsion therefore, where at all possible, to use existing or partly developed equipment arising from other projects.

4. The Black Knight Research Rocket System

Firstly, I would like to emphasise that the Black Knight rocket, and in fact any high performance rocket, had to be designed as a complete system. The launchers and the launching equipment, the ground handling equipment, the guidance system, the safety tracking equipment, the rocket test sites and so on, for Black Knight all had to be developed and working for the operations leading up to the first flight in September 1958. It is not possible in normal circumstances to make an uncontrolled projection firing for the first flight of a high performance ballistic rocket in the manner which has become normal for, say, anti-aircraft rockets. The high performance makes it necessary to apply at least good auto-pilot control or preferably a proper guidance system, in order to protect the boundaries of

the firing range from being violated. The Black Knight single-stage rocket could, if uncontrolled, reach anywhere within a circle of about 1,000 miles around the launch point.

Since most of the missile and ground systems have to be complete for the first flight, and the instrumentation to monitor them is clearly required, there is every encouragement to incorporate even the strictly unessential systems and to have the first flight a really complete system check in all respects. The only parameters which act against this situation are the practical limitation of monitoring channels through the telemetry system or systems, and the usual difficulty of ensuring that all systems are ready for the date of the first flight. In the event, the only system we did not operate on the first Black Knight was the re-entry head separation system, and this was largely dictated by the fact that we wanted to use all the available telemetry channels for monitoring the main rocket body functions.

In many ways, therefore, there is a distinct parallel between the development state for an initial aircraft flight and that for a ballistic rocket and this parallel gets closer as the aircraft gets necessarily more complicated, with power controls, auto-stabilisation and so on, and the pilot becomes more and more of a monitor rather than the brains and the source of most actions to the aircraft.

4.1. DESCRIPTION OF THE BLACK KNIGHT ROCKET

4.1.1. *First stage propulsion*

The propulsive system of the Black Knight was chosen with one main criterion; we wanted a reasonably efficient liquid-propellant rocket motor in a late stage of development, so that the design and development of the rest of the system could go ahead without further delay. We chose as the basis of the engine the Gamma motor on which the Rocket Propulsion Establishment, then the Rocket Propulsion Department of R.A.E., had done considerable development. The propellants used are H.T.P. and kerosine which have a theoretical specific impulse at sea level of 240 sec. at 500 lb./in.^{2}. The practical specific impulse obtained, although good for this mixture is not high by modern standards, but our initial performance calculations were sufficiently promising for us to accept this engine as a basis for design. However, the payloads that could be carried to our target speed of about 12,000 ft./sec. single-stage by a rocket powered by a single combustion chamber were too small, and in order to meet our requirement of approximately 150–300 lb. payload, four chambers were necessary. Since the turbo-pump assembly was only capable of supplying propellants to one chamber, we were forced, in order to avoid an immediate further development, to a four turbo-pump arrangement. Moreover, the motor had only been developed as a fixed engine, whereas we required swivelling jets for control purposes. The detailed engineering development of the four-chamber-four-turbo-pump engine from the original R.P.E. Gamma was done for the Royal Aircraft Establishment by Armstrong Siddeley, now Bristol Siddeley Ltd. Their work included the provision of swivelling combustion chambers and the building up of a four-motor installation named the Gamma 201, inside a propulsion bay provided to them, together with all the accompanying systems for starting and stopping the engine.

One powerful advantage which appeared from the four-motor installation was that to get pitch, yaw and roll control the engines only had to be pivoted about a single axis. This single axis could then be put more or less on the centre of gravity of the engine, and so the power requirements needed to swivel the engine were made as small as possible and also the inertial effects of the oscillating chambers on the missile flexural oscillations were also much reduced. It was also relatively simple to supply both propellants through the combustion chamber trunnions, thus obviating the need for long flexible high pressure pipes between pumps and chambers.

The engine (Fig. 5) is started from an external tank of pressurised H.T.P. through a probe into the propulsion bay—the H.T.P. is forced through a small silver-gauze catalyst pack on each turbine unit and the resultant high pressure steam drives the turbines. At the same time the start pressure is fed to a ring main which lifts the stop valves in between the four H.T.P. pump outlets and the chambers. As the pumps driven by the turbines speed up, the H.T.P. from the rocket tank is driven through the chamber catalyst packs and all chambers run "cold" on high pressure, high temperature steam. As the H.T.P. pump pressures rise above the start tank pressure, the pumps take over the feeding of the turbine catalyst packs and the engine "bootstraps," the start system becomes superfluous and is cut out by non-return valves. The rise in pressure in each H.T.P. delivery line from the pumps lifts the valves stopping kerosine delivery to the chambers and the chambers then run hot. To stop the engine a main solenoid valve is operated which cuts off the H.T.P. supply to the ring main, and vents it, so that all H.T.P. stop valves close. This solenoid valve is locked mechanically open during flight so that electrical failure will not stop the engine—an electrical pulse correctly applied will, however, always close the solenoid valve. During static firings a simple mechani-

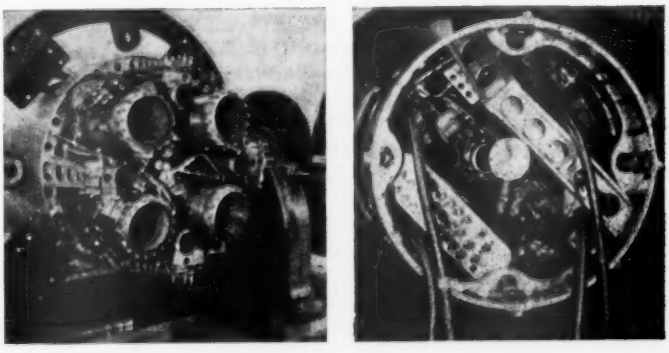


FIGURE 5. The Black Knight engine.

cal alteration is made; in this condition an electrical current failure will automatically close the solenoid valve and stop the engine. This is done to prevent an engine running away because of an electrical fault during the static firing.

When H.T.P. and kerosine are used as the propellants, the mixture ratio which is desirable is about 8 : 1, peroxide to kerosine. This has a marked advantage in propellant utilisation, for provided we over-fill slightly with kerosine, and guarantee therefore that we run out of H.T.P. first, the percentage errors in propellant utilisation operate only on the weight of kerosine carried, which is a total of over 1,000 lb. on Black Knight. Thus a ± 1 per cent error in mixture ratio leads to only 0 to 20 lb. of kerosine being left, provided 10 lb. extra of kerosine is carried above that estimated for perfectly correct mixture ratios; whereas the same error of one per cent in mixture ratio would lead to 0 to 50 lb. of remaining propellants if the mixture ratio of some other propellants was 1 : 1. Even if a gross error occurs which leads to a kerosine run-out first, the remaining H.T.P. will burn "cold" with a specific impulse of about half that of the proper mixture. The loss in specific impulse is, of course, serious, but retention of the unburnt propellant would be far worse. In setting the weights of the two propellants to be put in the Black Knight tanks due account is taken of a number of factors as follows:—

(*i*) The requirement for the H.T.P. to be depleted first.
(*ii*) The mixture ratio of the engine in the test bed.
(*iii*) The variation of mixture ratio with time during flight due to the different acceleration and pressure heads on the pump inlets.
(*iv*) The variation of density of the two propellants, as the pumps are volume rather than weight-measuring devices.

The attainment of accurate propellant utilisation is, of course, of supreme importance in ballistic rocket work; as an illustrative example a rocket with a 10 : 1 mass ratio (*i.e.* weight at T.O./weight at all-burnt) with accurate propellant utilisation, will, if one per cent of the total propellant weight is left in the tanks, have an effective mass ratio of only 9·17 : 1 and will have a reduction in velocity of about 5–6 per cent compared with the perfect case.

4.1.2. *Main missile structure*

The major part of the 30 ft. length of the Black Knight single-stage rocket is in the kerosine and H.T.P. tanks. The H.T.P. tank is 17 ft. long and 3 ft. in diameter and is pressurised to about 10 lb./in.^{2} relative to ambient. This pressure provides the minimum inlet pressure to the H.T.P. pumps and helps to stiffen the tank against inertia loads from the front of the missile and against the bending loads. The kerosine tank is 4 ft. long and is unpressurised but is kept about +2 lb./in.^{2} relative to ambient for most of the flight by a blow-off valve which is set at this level; this tank is above the H.T.P. tank. The tanks are not stiffened by stringers and have only rings to ensure retention of the circular cross section; the external stringers seen on the missile are non-load bearing and cover electric cables and four kerosine pipes, one to each turbo-pump. The H.T.P. is taken by a large 3½ in. pipe out of the centre of the bottom dome of the H.T.P. tank and is connected by a steel, flexible pipe to a four-way elbow with a diffuser into the four H.T.P. pump inlets. A small unpressurised intertank bay put in to avoid a difficult leak protection problem from the kerosine into the H.T.P. tank, is used to house the nitrogen pressurisation bottles for the H.T.P. tank. Both propellant tanks are provided with anti-vortexing baffles and sumps to prevent vortex formation as the tanks are running dry.

Above the kerosine tank is a pressurised equipment bay which carries the auto-pilot, the radio command link receivers, the main telemetry and so on; this compartment is sealed on the ground to ground level pressure and holds its pressure for the whole of the flight of about 20 min. The equipment bay is pre-cooled on the ground by a Freon cooling system, the heat being exchanged by a radiator over which the internal air is circulated by a fan. The system is disconnected just before launch, but the compartment remains sealed as only the primary Freon circuit to the radiator is then open to atmosphere. Fixed to the top of the equipment bay is the transition bay, which adapts the missile to any payload provided.

The propulsion bay is fitted to a strong ring at the bottom of the H.T.P. tank by bolts. The engine loads are carried from a central spider, to which all inner trunnions of the four chambers are fixed, up four tubes to the top of the propulsion bay and from the outer trunnions up four main longerons into the same stress diffusion areas. On the launcher the whole weight of the missile is taken by a suspension ball fixed to the central spider; four wind braces are used to steady the missile laterally, but they bear no part of the weight. During static firings half the engine thrust runs straight through the spider into the launcher structure; the other half is taken round the longerons and back down the tubes to the spider and ball.

The four thrust chambers are canted so that their thrust lines pass approximately through the position of the centre of gravity of the missile at all-burnt (although their axes are not altered as payload weight is altered); this is done so that no large pitching moments are produced if the engine cut-off is ragged, as this might complicate separation of the re-entry head or a second stage.

The majority of the structure is manufactured from aluminium alloy, welded from sheet to form tank shells, spun to form tank domes or machined from forgings and so on. Many of the sheets are chemically milled to lighten the structure, as the original plate thickness is in many places decided by the reduction in strength due to the inert gas welding.

4.1.3. *Control*

The Black Knight rocket is controlled at all times by the single axis swivelling of the four thrust chambers; one opposite pair give control in pitch, the other opposite pair give control in yaw, and all chambers moving clockwise or anti-clockwise give control in roll. Aero-

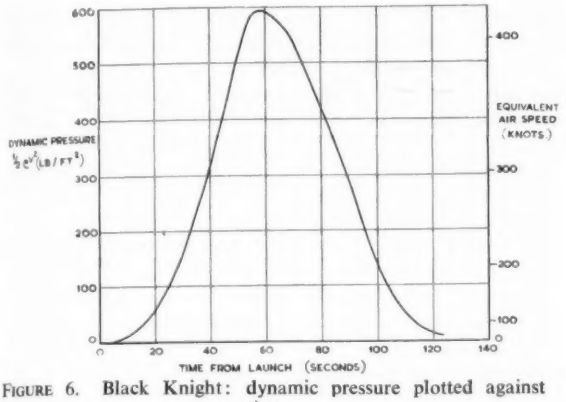


FIGURE 6. Black Knight: dynamic pressure plotted against time.

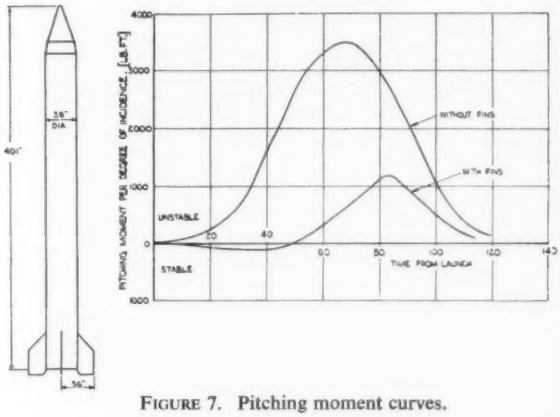


FIGURE 7. Pitching moment curves.

dynamic control surfaces are not provided, although Fig. 6, which shows a typical variation of dynamic pressure ($\frac{1}{2}\rho V^2$) with time, indicates that for the middle part of the flight only, their use might be possible; we did not consider that their development would be worthwhile. Fins have, however, been provided to improve the stability of the body; reference to Fig. 7 will show that despite the improvement in stability provided, the body is still unstable at high Mach numbers, but the improvement serves to reduce the demands made on the control system in two ways: —

(*a*) it reduces the angle to which the motors must be moved to hold the heading steady in a gust,

(*b*) it reduces the rate of movement of the motors necessary to prevent heading divergence, by reducing the natural rate of divergence with fixed motors.

The two pods on one pair of fins carry a radar transponder and other instrumentation such as occasional extra telemetry senders; these pods provide small gratuitous stabilising moments in one plane.

The motors are swivelled by hydraulic actuators which were developed originally for the R.T.V. and G.P.V. vehicles. The hydraulic pressure is supplied from an accumulator charged by two pumps attached one to each of the yaw motor turbines. The polarised relays on the actuators are directed from servo amplifiers located in the equipment bay in the forward portion of the rocket. Stabilisation of the rocket is achieved by mixing two inputs in the servo amplifiers: —

(*i*) The output of the space gyros located in the forward equipment bay.

(*ii*) The differentiated output of the same space gyros which give derived rate terms instead of using rate gyros as such.

The first inputs (*i*), of course, keep the heading steady in pitch, yaw and roll; two Reid and Sigrist gyros in different orientations are used to supply the three heading references. The second inputs (*ii*) give the damping terms necessary to dynamically stabilise the oscillations in heading. This control system is basically provided to stabilise the rocket in desired headings in pitch, roll and yaw, while the rocket is being subjected to external aerodynamic diverting moments due to wind shear, gusts and aerodynamic asymmetries and moments arising from offsets of the thrust lines due to internal motor asymmetries and control system offsets and drifts. The wind shear term is a particularly large one as the rocket is required to maintain control as it rises through a "jet-stream"; due to a large effective "wing loading" it has a very long time constant in response to a side gust and a high proportion of the wind shear is left as an effective gust velocity due to the rocket's slowness in picking up the lateral velocity of the wind. The design of the system is complicated by the tendency for the control system to excite oscillations of the body both in free bending and torsion. To avoid trouble due to this excitation, the frequency response of the control system and its shaping networks has to be such that all the possible structural excitations are well damped. It follows that the position of the angular rate sensors (differentiated space gyros for Black Knight) has to be chosen so that at all frequencies over which the motor control system has appreciable response the outputs of the sensors, in conjunction with the servo responses, act in a damping sense; this implies that the sensors have to be at particular places on the rocket dictated by the shape of the bending and torsion modes of the rocket. The problem was eased on the Black Knight rocket by two factors, the minimising of the inertial excitation forces arising from motor oscillation referred to in Section 4.1.1, and the reduction in the maximum response of the motors due to the provision of fins mentioned in (*b*) above.

In practice satisfactory positions were obtained with gyros placed in the forward equipment bay; some trouble was experienced due to the gyro noise being amplified by the differentiating network, but this was overcome by careful gyro and shaping network design.

The investigation of control performance had to be made over the complete range of tank levels using the relevant aerodynamic stabilities and for the worst disturbances; as the weight of propellants is a very high proportion of the all-up weight (about 90 per cent), the frequencies and shapes of the bending modes change markedly with time of flight. Due account of this must be taken in the stability investigation but the problem

can be eased by varying the gain in the servo loops with time of flight. There remains the problem of the control stability while the missile is on the launcher; it has to be satisfactory or the problem has to be avoided by closing the full control loops only immediately after launch. On Black Knight, although the stability was more critical on the launcher than in flight, we were able to close the loops stably on the launcher, and this made possible a check on each missile with all engines operating before launch, and thus ensured that the individual variation in performance of all the components of the control system and the relevant parts of the structure did not make the overall system unsatisfactory. This appears rather better than relying completely on tests showing that the performances of blocks of the control system are within specification.

4.1.4. *Guidance system*

The previous section described the auto-pilot system used to stabilise the Black Knight. If the auto-pilot gyros had been sufficiently drift-free in all conditions of missile acceleration so that deviations from the desired flight-path were restricted to within those tolerable (from range safety and ground instrumentation considerations), extra guidance might not have been necessary apart from the provision of a missile borne programme unit to give the desired heading variations with time, although it would have been necessary to predict wind effects. However, we did not wish to rely on very accurate gyros for a basic research vehicle, and an external monitoring system was used; this was also used to provide changes of flight path and no programme unit controlling heading is incorporated in the missile. Fig. 8 illustrates the guidance scheme.

The main guidance is achieved by command controlling the missile to follow a beam aligned to the desired elevation and azimuth at cut-off. The elevations and azimuths are selected to give impact about 60 miles down range from the launch point, and are varied with expected missile performance; due account has to be taken of the earth rotation that occurs for the approximate 20 min. between cut-off and impact. The elevation has varied between $88\frac{1}{2}°$ and 85° for various firings up to the present time, with varying payload weights. No engine cut-off signal is supplied from guidance information and the tanks are allowed to run to depletion; any variation from expected performance will cause an uncorrected dispersion in the pitch plane, again with notice taken of earth rotation effects. Command control is only exercised in the pitch and yaw planes; the auto-pilot is relied upon to hold the missile roll stabilised with sufficient accuracy so that angular phasing errors between the pitch and yaw commands do not cause instability.

In detail, two beams are set up using two alternative systems; one is a radar beam set up by pointing a carefully calibrated SCR584 radar dish in the required direction, and the other is an optical beam set up by a high power telescope pointing in the same direction. The angular position outputs obtained from the radar error signals are multiplied by the radar range to give lateral displacement from the beam in two perpendicular directions and these values are differentiated to give lateral velocities. In the optical system an operator observes the rocket flame or a specially installed tail-light through the telescope, and moves grid wires to coincidence on the light; the output of a sensor measuring grid position is operated upon in a similar way to the radar information and, using radar range or a programme giving expected range, gives the same outputs of lateral position and lateral velocities as the radar system. The outputs are displayed on scopes to two human operators, a pitch controller and a yaw controller; they operate "joysticks" which send up/down and left/right command signals to the missile through a radio command link channel by means of coded tones on a single carrier. If, say, the pitch controller's "joystick" is central, no pitch commands are sent, but if it is placed to one side a series of up pulses, or vice versa, are sent at a fixed rate of 4/sec.; each pulse when received by the missile is converted by a rampager unit into an appropriate bias on the pitch space gyro output of $\frac{1}{4}°$; thus a pitch heading change is requested which is proportional to the time of dwell of the

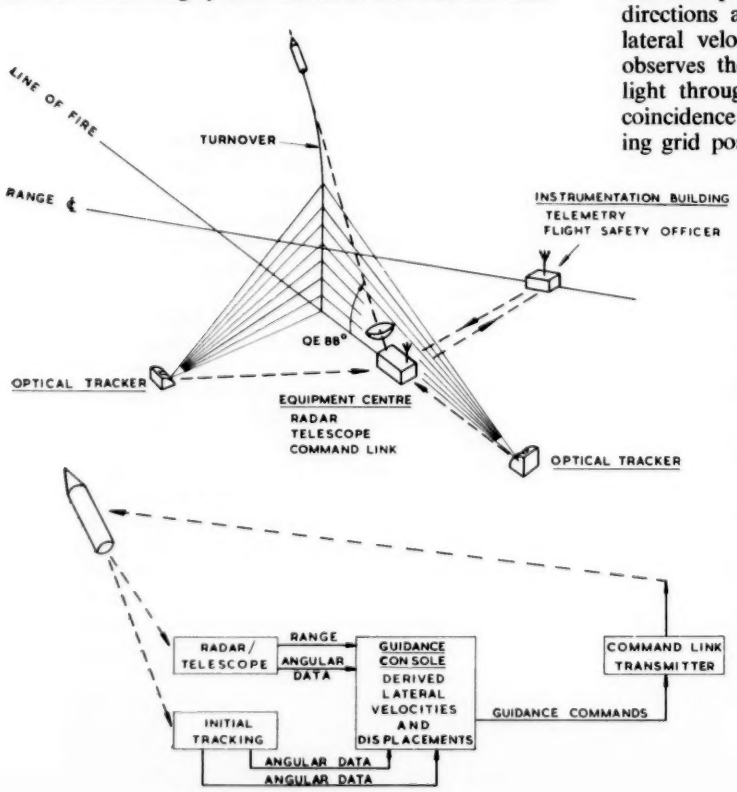


FIGURE 8. Command link guidance system.

joystick on the up side or down side. The operators control mostly in an effort to reduce the lateral velocities to zero, for the errors in lateral position relative to the beam only result in almost identical impact errors, whereas the impact error due to a given lateral velocity error is that error multiplied by the time of flight, *e.g.* a 10 ft./sec. lateral error (pitch or yaw) and a time of flight of 1,000 sec. gives a two miles impact error. The main reason for applying guidance commands in a direction to reduce lateral position errors, is to keep the rocket within the beam width of the two systems. At any one time the monitoring is done either from radar or from optical information, but either system can be selected at will.

During the early stages of take-off the missile flies almost vertically and is below the main guidance beams, which are anchored in the blockhouse, some 200 yards up range from the launcher. To get tracking information during this early phase, two optical M2 trackers are set, one to the rear and one to the side, and these give azimuth and elevation deviations respectively, which are operated upon in a similar manner to the outputs of the main trackers. When the rocket is seen to rise into the main beams, information from the initial M2 trackers is switched out and the main beam information is substituted; at the same time the pitch controller begins to correct the step-function change in pitch lateral velocity which occurs at this change-over due to the change in axes, and the missile is automatically turned over into the correct elevation angle.

All the Black Knight firings have been done at night and in clear conditions which give good optical tracking, and we have found that the optical guidance system is the most accurate; this system is now used as a primary system with the radar system used as a standby, although its range information is used throughout. All Black Knights except the first have fallen within ± 4 n. miles of the expected line in the yaw plane; the deviations in the pitch plane have been greater, ± 15 n. miles, due mostly to scatter in the forward, all-burnt velocities. Before any flights were made at all, a complete two-plane simulation of the whole of the guidance loop was made, including the human links; this simulator has been used to select and train the human operators, although it was found that a majority of those who attempted the operator's job could do it quite well after a little training. In the near future we expect to replace the human operator by an automatic closed loop system; the human operator moving the grid in the fixed telescope will, however, be retained.

4.1.5. *The second stage*

The second stage of the Black Knight in the present configuration is built round a solid motor developed by R. P. E. Westcott called the Cuckoo. (Fig. 9 shows the Black Knight in the two-stage configuration.) It is 3 ft. long and 1·4 ft. diameter; the burning time used is 5 sec. Up until now the second stage has only been fired late on the downwards path so that its burning is only just finished before nominal re-entry occurs at about 40 n. miles altitude. In this application the motor is mounted upside-down, that is with the venturi facing forward,

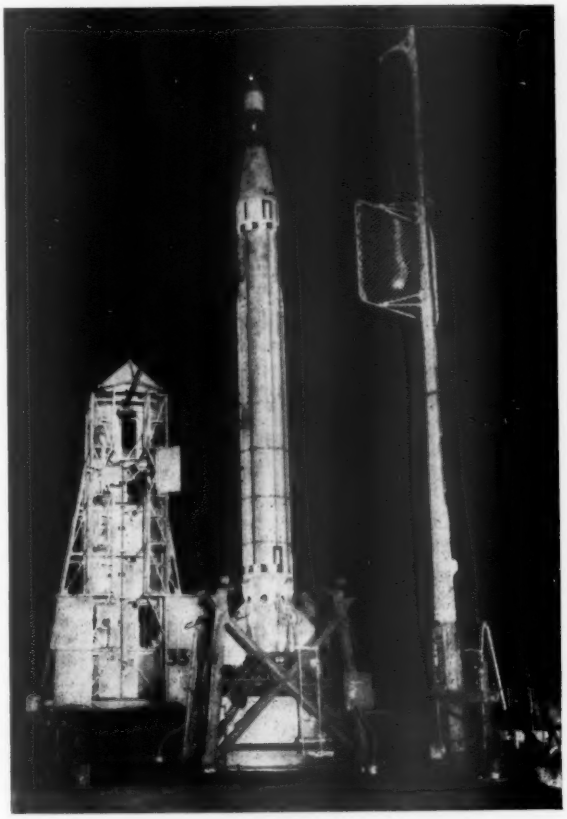


FIGURE 9. Black Knight: two-stage configuration.

and mounted on a short skirt which mates with the adapter bay on the first stage; the venturi is covered by a fairing. The motor case of the second stage takes the structural loads. The payload of the second stage is mounted on the end of the motor, that is, is carried downwards, projecting into the transition bay. The second stage is separated at all-burnt on the ascent at about 60 n. miles altitude by detonating exploding bolts; the stage is then both spin-stabilised at a spin rate of 150 r.p.m., and separated from the first stage by an addition of about 8 ft./sec., by opening up two downwards tilted peripherical jets supplied by compressed air contained in a bottle mounted inside the venturi fairing. Fig. 10 shows a frame of a film taken of a test of this separation system in a simple rig at the Saunders-Roe Division of Westland Aircraft Co. In this test the second stage is allowed to fall a short distance and then the separation and spin-up system is started and the resultant motion observed. Aerodynamic forces are negligible in this test, as they are in flight, and such a test is typical of the simple and realistic separation tests that can be performed on the ground. After separation from the first stage the second stage rises to an apogee of about 350 miles (the first stage does about the same) and is ignited at about 65 n. miles on the way down by detection of the beginnings of atmosphere by a Phillips ionisation gauge—the density of the air is magnified by

using a Pitot entry to the ionisation chamber and so lowers the necessary sensitivity of the instrument; the level of the detector is set so that burning of the Cuckoo finishes before re-entry proper starts. During the ignition, the venturi fairing and the now exhausted spin stabilisation system is blown off, thus improving the mass ratio and the performance of the second stage. The payload is detached from the Cuckoo boost by explosive bolts and separation springs. Special precautions were taken to prevent air leakage from the pressurised payload capsule and the Cuckoo motor from increasing the local ambient pressure to such a level that inaccuracy in the trigger level of the ionisation gauge occurred; careful sealing and shielding plates were both used.

This downward firing technique was used so that dispersions of the second stage due to inaccuracy in the launching angle from the first stage could only take effect in the distance down to the ground from the 65 n. miles ignition altitude. If the second stage had been fired upwards on the ascent immediately after first stage shut-down, the re-entry speed would have been the same as with the downwards firing, the maximum altitude would be of the order of 1,500 n. miles and errors in the launching angle would have been felt over an effective 3,000 n. miles distance. For example a 2° error in launching angle would lead roughly to an additional 2 n. mile dispersion with the downward firing technique, but an extra 100 mile dispersion with an upward firing technique.

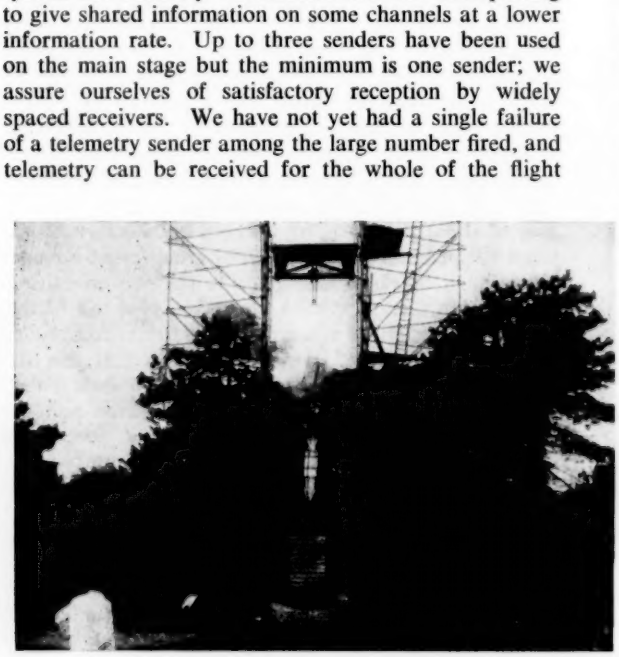
4.1.6. *Missile instrumentation*

The main body instrumentation system is based on the normal types of sensor elements connected into one or more R.A.E. sub-miniature telemetry systems. This system has basically 24-channels with sub-multiplexing to give shared information on some channels at a lower information rate. Up to three senders have been used on the main stage but the minimum is one sender; we assure ourselves of satisfactory reception by widely spaced receivers. We have not yet had a single failure of a telemetry sender among the large number fired, and telemetry can be received for the whole of the flight path. For single stage rounds with separating payloads a telemetry sender is normally carried in the payload capsule, but for two-stage re-entry experiments, the telemetry equipment is replaced by a tape-recording system as the telemetry signals would be absorbed by the strong ionised sheath during much of the re-entry. The tape recording system used has the same data capacity as the telemetry system. The magnetic tapes are contained in an armoured cassette and recovered on the ground after flight.

In addition to the telemetry information, tracking by radar and optical systems is used to evaluate trajectory, and special systems such as pyrotechnic flare ejectors, powerful electronic flashers and tail-lights are carried in the rocket or payload to ease synchronisation problems; much help in tracking is also given by the very bright self light generated by the ionisation during re-entry.

4.1.7. *Ground facilities*

In order to develop and use Black Knight, extensive, but economic, ground facilities have been installed, in addition to the normal existing manufacturing facilities. These begin with the engine test stands at Bristol Siddeley, one of them a vertically downward firing stand capable of taking a complete propulsion bay. On these stands the engine was developed and production engines are calibrated. The main contractors, the Saunders-Roe Division of Westland Aircraft Co., have built a missile test site on the tip of the Isle of Wight, at Highdown, near the Needles (Fig. 11). At this facility there are two test stands in addition to test shop facilities and so on. These two stands are equipped with fixed gantries, which are in effect sheds with access platforms, built round the missile in its vertical position on the launcher and its emplacement. We regard these as vertical test shops where all the missile systems can be checked and a complete count-down be conducted in circumstances completely representative of a firing on the range. Static firings can be made on these stands, the exhaust flames being deflected through 90° and out across the cliffs by a short, water jacketed and spray cooled elbow; the water pumping rates available are up to four times the total propellant flow rate. These stands are again used



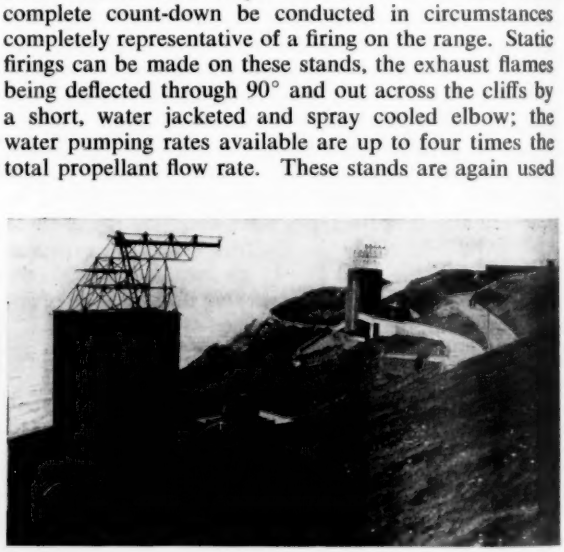


FIGURE 11. Highdown test site, Isle of Wight.

FIGURE 10 (*left*). Second stage separation test.

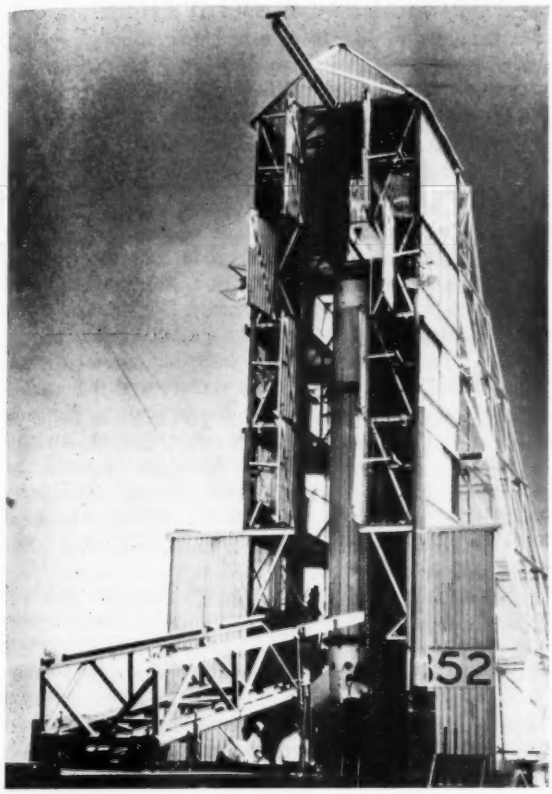


FIGURE 12. Woomera: Black Knight in gantry.

for both development tests and the acceptance tests of flight missiles. The acceptance tests of the rockets are carried out on these stands with every system complete and they are then transported to Woomera in one piece, apart from some minor removals to ease packaging problems, travelling either by air or sea. At Woomera, after checkouts in a test shop to assure ourselves of satisfactory transportation and after the range authorities have made this safety check, the missile is erected on one of the two launchers. At each launcher there is again a similar facility for engine static firing to that at Highdown, but at this site the gantries are removable (Fig. 12) to remove obstructures to firing, and an umbilical mast is provided to hold up the electric cables and the freon cooling system. A catch net is provided to catch the heavy multi-way plugs which are ejected just before launch.

All missile firing operations on both launchers are controlled from the blockhouse (called the equipment centre) (*see* Fig. 13) which is tied to the main range operating room in the Range Instrumentation Building. During the immediate pre-launch sequence a number of vital checks have to be made such as:—

(*i*) check that the start system has charged,
(*ii*) check that the tanks are pressurised,
(*iii*) check that all engines have risen to minimum power,
(*iv*) check that hydraulic pressure is obtained,
(*v*) check that all motors are central,
(*vi*) check that umbilicals have been removed,
(*vii*) check that engine start system is ejected,
(*viii*) check that all electrics have gone over to internal power supplies,

as well as the timing and sequencing of all the operations needed to operate the ground and missile systems and finally to release the catch holding the main suspension ball on the spider in the propulsion bay. We decided right from the start of development to have this complicated pre-launching sequence fully automatic, in order to eliminate human error in these critical and pulse-stirring seconds; we do, however, use the firing team as monitors on the events with the facility to apply a stop action if necessary. So from minus two minutes from engine start, all executive actions are controlled from a master sequencer which issues command pulses to all systems, and checks that these actions have been satisfactorily performed before giving out the next action. If all actions are satisfactorily made, the release catch is released automatically and the post-firing actions for the ground system ordered. If any action fails, the interlock system stops the sequence and returns the whole system to a safe situation. In fact only the long term items such as fuelling, and telemetry switch-on are manually arranged, together with certain long term actions on the ground systems. During an actual firing the sequencer in the equipment centre is supplied with time impulses from the master sequencer at the range-head, so that the complex requirements of range and missile are met together; stop action can be applied by the range control by cessation of the supply of time impulses.

The automatic system has proved of enormous benefit and no system malfunction has remained undetected and no mistakes in sequence have been made; the odd failure has occurred in the sequencer itself, but it is designed to fail safe, *i.e.* it prevents the sequence carrying on, which aborts the firing but does no damage at all. The local equipment centre automatic system was originally developed by Saunders-Roe and installed at the Highdown test site and has been used throughout the

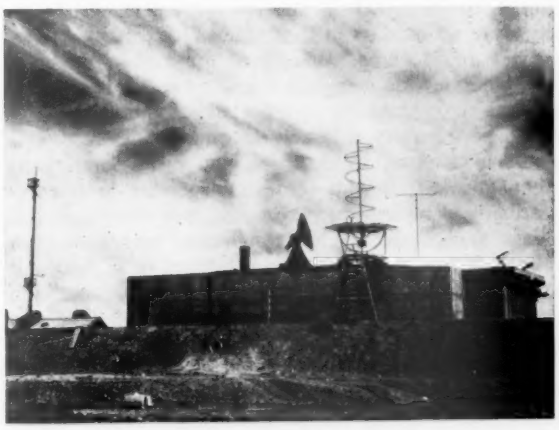


FIGURE 13. Woomera: Equipment centre.

development of Black Knight and is used for all acceptance static firings, and I am sure it has contributed very largely to the success of the Black Knight launchings.

5. Black Knight Firings

The project started in mid 1955, and the first engine run took place in November 1956. The first static firing of a missile took place at Highdown in April 1957, and the first in Australia on a proving missile in June 1958.

The first flight firing took place in September 1958; this flight was terminated a little prematurely when 90 per cent of the propellants had been burnt, by a malfunction of the safety destruct system which correctly responded to a false cut-down signal. Since the first flight, 7 more have taken place, 2 of which were two-stage rounds. On all but one of these flights all the propellants were burnt except for remnants of kerosine; on one occasion one chamber completely shut down, but the rocket behaved perfectly well on the other 3 chambers, and went on successfully to propellant exhaustion, fully under control, and guiding correctly. The first two flights were entirely given over to proving the main stage systems and guidance; all the last six have been combined experiments covering many, if not most, of the problems listed in Fig. 4; all carried re-entry heads. Of the 2 two-stage rounds, one, the last, was completely successful. The last three Black Knights have carried upper atmosphere experiments.

The single stage rounds, with normal payloads, in practice reach 12,000 ft./sec. in a near vertical firing (*i.e.* when the gravity losses are the greatest); this was our target figure for our original design calculations. The rocket rises to a maximum height of about 600 miles in this role. With heavy payloads such as the two-stage round, the maximum speed reached in the first stage is about 9,000 ft./sec., and the maximum altitude reached by both stages is approximately 350 n. miles. During second stage burning the speed is increased from 9,000 to 16,000 ft./sec. or greater depending on the payload carried. The take-off acceleration in all roles is very low so as to get maximum performance out of the installed engines.

The fact that the Woomera range is a land range has gained us more than steady instrument platforms anywhere we like to put them; it has also enabled us to recover an enormous amount of the broken up body pieces besides the complete re-entry heads, these latter without the parachute systems and flotation bags on which sea recovery is largely dependent. More or less complete combustion chambers and turbo-pump units are recovered but with some damage due to re-entry heating; a complete Cuckoo motor case was recovered, almost undamaged due to its high drag properties, even though it re-entered at approximately 16,000 ft./sec. All tape recorders have been recovered in good condition again after re-entry speeds of up to 16,000 ft./sec. and excellent records obtained from the tapes. This large scale recovery of pieces has been of considerable help in investigating minor failures, as the number of telemetry channels can never be sufficient to instrument every part and function of the round.

6. Ballistic Missile Research Problems

I should now like to turn to a few chosen problem areas, to discuss these basic problems and to illustrate how flight testing and in particular the Black Knight Rocket has helped in our understanding of them.

6.1. FUEL SLOSHING

With a liquid fuelled rocket which is pump fed, there is generally a free surface in each of the missile tanks, so that when the rocket is excited in rotation (pitch or yaw) or especially by lateral motion, the liquid slops to and fro in the tank—*i.e.* it sloshes. The motion of the liquid is directly affected by the longitudinal acceleration of the missile as the restoring moments are proportional to the angle of the surface and the applied longitudinal acceleration. The frequency and damping of the slosh is dependent on tank dispositions relative to the missile c.g., the level of propellant in the tanks and the adpressed acceleration. Of course, deliberate oscillation of the control system or external excitation from gusts at the resonant frequency of the " slosh " will cause it to build up.

Calculation of the damping of the fuel sloshing modes, including the control system, can be made and were made for Black Knight and showed some interesting properties typical of many missile configurations. Fig. 14 shows the results for the most critical mode in a typical Black Knight two tank case. It can be seen that early on in flight and for most of the late part of flight, the slosh mode is positively damped though often very slightly so, but during the middle part of flight it is slightly negatively damped. On first thought, the existence of negative damping appears to be an undesirable situation, but it can be shown that if a small impulse is supplied at the beginning of the unstable period, the damping is so slightly negative and the period long ($\frac{1}{2}$ second), that the amplitude of the oscillation has only increased by a factor of 2 or 3 by the end of the unstable period. Thus it does not appear at the second look as a dangerous situation. If, however, one further considers the problem of not a single impulse, but a series of random impulses both in phase and frequency, which is probably near to what might be expected from gust or command control excitations, or one considers a series of resonant pulses which might perhaps occur occasionally, there appears to be little difference between having small positive or small negative damping, for the response of a system with either is similar for the first few resonant excitations. It is possible, however, to assume a reasonable looking excitation programme that might cause large and dangerous amplitudes. As a further complication, ground tests showed that the damping of sloshing in either plain or baffled tanks was only linear over a small angle of slosh; after $\pm 10°$ or so of surface movement, wave-breaking occurred, and the damping showed a marked increase; the wave-breaking is, however, markedly affected by the adpressed longitudinal acceleration.

Faced by this situation there is a tendency to play for safety, and fix slosh damping baffles in the tanks to give an increase over the natural, plain tank damping.

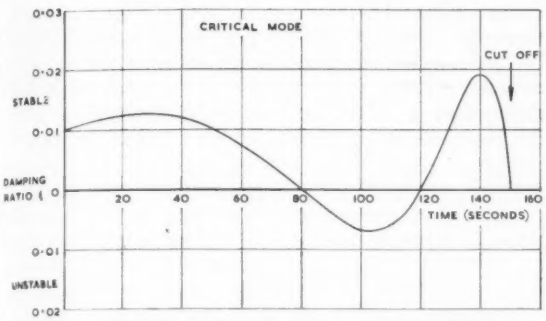


FIGURE 14. Black Knight: slosh damping plotted against time (theoretical).

On Black Knight we decided to fix slosh dampers initially in the H.T.P. tank, and to make a later test, after we had overcome the first hurdles of missile development, with all the slosh dampers deleted. We developed very efficient dampers giving about one per cent of critical damping over the entire period of flight, which consist of fingers stuck out from the tank wall into the liquid, but since all dampers are only effective when they are within a small distance of the surface, these dampers were fitted in an effective spiral down the tank to cover the range of tank levels over which we expected negative damping.

Figure 15 shows a typical record of the motor movements as a function of time taken during a flight of Black Knight with the original baffling scheme fitted. It can be clearly seen that fuel sloshing is causing a regular and appreciable though not dangerous motor movement of about $\pm 1\frac{1}{2}°$ (equivalent to $\pm 0{\cdot}1°$ of heading) over the period for which small positive damping was calculated, but that as the H.T.P. level comes down to the slosh damper level, there is a fairly sudden and marked break up of the record and gradually a reduction in the amplitude of slosh effects. Provided our slosh mode damping estimates were right, this indicated that there was little difference between having small positive and somewhat larger positive dampings but that the excitation was sufficiently random for serious oscillation not to occur. This flight record is typical of all of the Black Knight flights with this damper configuration. We decided, therefore, that this estimation of the situation could be confirmed just as well by extending the slosh dampers further up the tank walls so that extra baffles would be in use during the period covered by the more vigorous oscillation of this record. This was done and one flight in this new configuration gave the lower record—this shows a continued broken, somewhat lower amplitude level for the whole of the period for which oscillation tends to occur. We therefore consider it likely that the Black Knight missile would behave perfectly well without any slosh baffles at all, though it would oscillate appreciably, and that the presence of a small negative damping in a long period motion of this nature is unlikely to be dangerous for any ballistic missile. It is obvious, however, that at no time must heading commands in pitch or yaw be fed from command signals or programme units in resonance with the sloshing frequency, for the small damping coefficients present, negative or positive, will not prevent very high resonant response.

6.2. BASE HEATING

Before flight tests were made in this country, the base heating problem was only partly understood and only partly explored theoretically. The main cause of

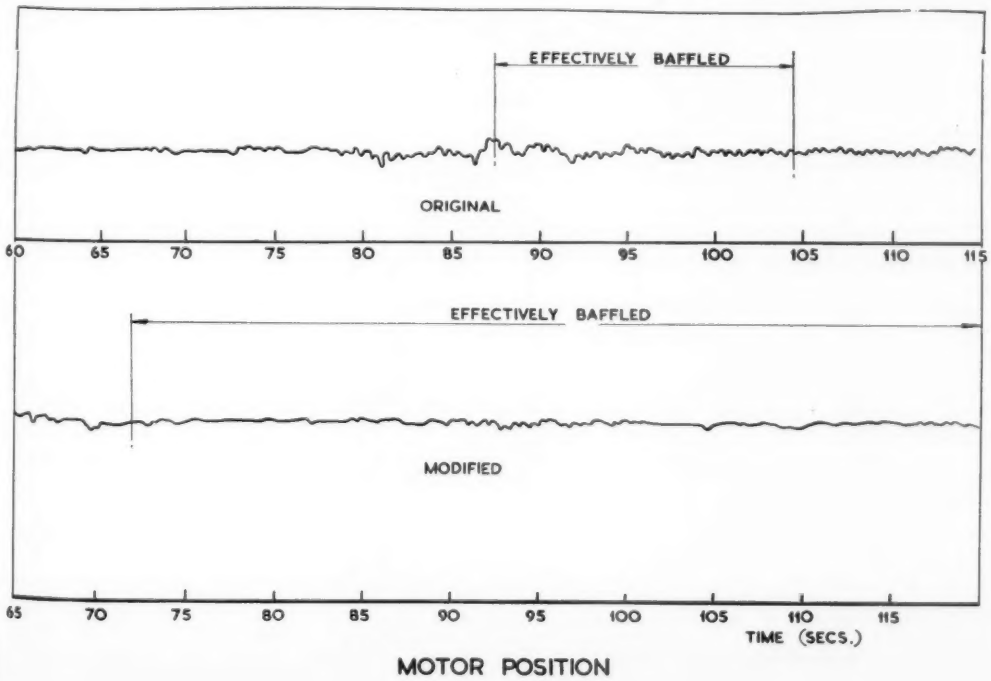


FIGURE 15. Black Knight: slosh amplitude plotted against time.

base heating stems from the fact that at great altitudes, the rocket nozzle exhaust is under-expanded and a further expansion takes places outside the nozzle. Two main régimes of flow exist, however, with gradual transition between them:—

(*i*) when the ambient pressure is low, but the external flow is supersonic and has sufficient dynamic head to cause interaction between the trailing edge shock from the missile skirt and the expanding flow from the rocket nozzle;

(*ii*) when the ambient pressure and external flow influence is negligible and the sole effects are due to the expanding nozzle flow.

In the first régime (*see* Fig. 16(*a*)) the interaction causes trapped vortex flows to carry the hot, mixing regions of the outside of the jet flow back onto or into the base of the missile itself; it will, particularly, trap low velocity jets such as may be issuing from turbine exhausts, heat exchangers and so on, and carry these hot gases bodily back into the base, making the convective and radiant heat transfer problem much greater. This part of the problem was more or less understood before the Black Knight first flew, though the complexity of the flow patterns is such that theoretical studies do not get very far. However, wind tunnel studies were made at the R.A.E. to investigate this problem. Two methods of solution were available: the first, to seal off the base by a firewall and to design this to accept both the convective and the radiant heat exchange involved. This involves a heavy weight penalty and reasonable care has to be taken to avoid leakage of the hot gases into the propulsion bay while still making it possible to swivel the chambers. The second was to attempt to sweep away and prevent the formation of trapped vortex flows by venting the propulsion bay with fresh though increasingly hot air from the external flow. A practical solution of the second kind was found for Black Knight during the wind tunnel tests, by opening up eight circular flush intakes in the forward end of the propulsion bay: this cleared the outer annulus but a more difficult area in the centre, in between the four chambers, was dealt with by placing a local fixed baffle there. The flight tests of this arrangement showed it to be very satisfactory over the range of altitudes where the first type of flow exists; in fact the conditions in the centre were rather better than we expected. At low altitudes and speeds, before a large volume of air was flowing through the flush intakes, the centre baffle began to heat up, but as the strength of the cooling flow increased the baffle actually began to cool again, quite rapidly.

The second régime of flow, however, showed itself to be more troublesome in flight. First (*see* Fig. 16(*b*)) the flow expanded through a greater angle at the jet exit plane than we calculated, probably due to the boundary layer flow in the jet and, secondly, the coalescence of the four jets in the centre, preventing their further expansion, set up a relatively high pressure area and sent a hot jet directly forwards onto the centre baffle. We had a structural failure of this centre baffle due to the heating, but a simple added protection immediately stopped further failures. At the same time, the absence of significant external flow and the supply of relatively high pressure gases from the rocket exhausts caused the flow inside the propulsion bay to reverse and pass out through the flush intakes. On later flights we have fitted

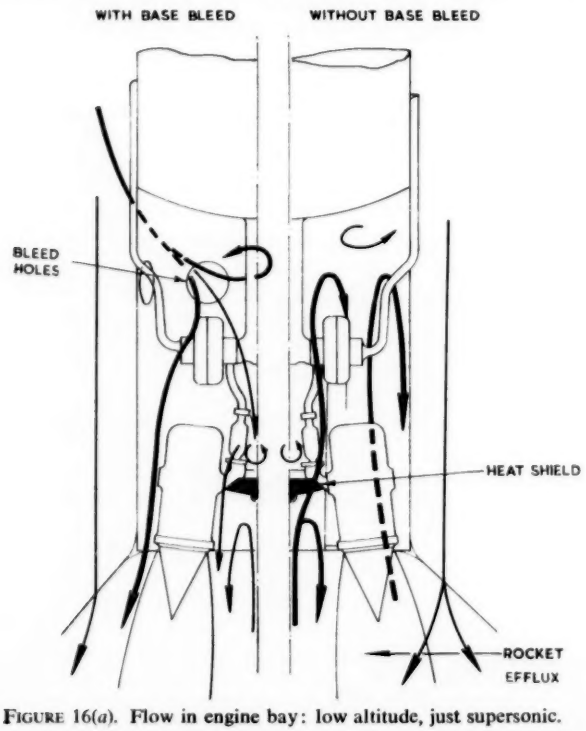


FIGURE 16(*a*). Flow in engine bay: low altitude, just supersonic.

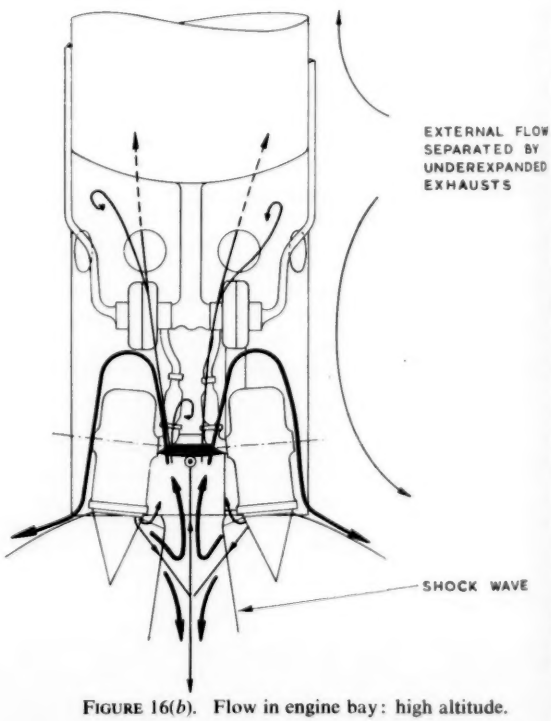


FIGURE 16(*b*). Flow in engine bay: high altitude.

spring loaded doors on these intakes which automatically close as the flow tries to reverse. There is clearly much more to be learnt about these complex flows both in flight and on the ground. Many experimental investigations can conveniently be done in very high vacuum chambers on the ground, and this type of ground testing is going on both in this country and in the U.S.A.; some interesting articles have appeared in *Aviation Week* about tests being made in the U.S.A. facility of the Arnold Engineering Development Center.

6.3. THRUST DRIBBLE AFTER CUT-OFF

When a rocket motor is shut down or runs to propellant depletion, there is an expected decay time for the thrust to run down to near zero; the repeatability and the duration of this decay process can be tested for on ground facilities, and is an important part of the engine testing. However, as the combustion chamber pressure in flight drops below 14 lb./in.^{2} (the ground level ambient) the flow passes into a régime which is not represented properly in normal engine testing on the ground. We know, of course, that the chamber pressure has to get down to local ambient (almost absolute zero in most flight cases) and a number of processes occur as follows:—

(*i*) There is straightforward completion of burning in the chamber and the decay of the pressure due to the expansion of the burnt gases in the chamber.

(*ii*) There is a continued and perhaps inefficient burning of some propellants that are bound to leak into the chamber from the pipes and injection passages downstream of the cut-off valves.

(*iii*) There is a conversion of the chamber heat capacity into thrust energy by the evaporation or boiling of the liquids around the chamber.

In many cases, the integration of all these effects may only amount to a small total impulse on the missile, but since many separations of re-entry heads, upper stages and so on, could otherwise be effected by small impulses, severe interference could occur with the separation process if these thrust dribble effects are neglected. On Black Knight the effect (*iii*) is very marked, for as the remnants of the H.T.P. are forced out by boiling, part of the chemical energy of the H.T.P. is efficiently converted into heat energy and thrust as it passes through the catalyst pack.

Figure 17 shows an actual flight record taken on Black Knight in which the thrust dribble is measured by a sensitive accelerometer. The very long duration of the tail is notable. We have found as might be expected, that the missile control system will stabilise the rocket under these low thrusts as long as hydraulic pressure is left in the accumulator, though the system becomes increasingly dynamically unstable at an ever lengthening period as the thrust drops. Some Black Knights have been stabilised, albeit imperfectly, up to 100 miles after cut-off by this means.

The two important, resultant effects that have to be considered here are:—

(*a*) the interference with the separation referred to,
(*b*) the effect on the accuracy of cut-off if, say, an attempt is being made to put a satellite into a precise orbit.

The first effect (*a*) can be dealt with in three main ways and there may be others. Firstly, by increasing the separation impulse (*i.e.* applying an extra relative separation velocity on the separating re-entry head or stage) so that this impulse is greater than the integrated thrust of the dribble after separation is effected; this separation velocity can be supplied in parts to body and head. Secondly, we can apply a smaller separation impulse and rotate the discarded stage after sufficient clearance has been obtained. Thirdly, we can compress all the tail effects into a short interval and commence the separation process after this interval; this can be done by quickly blowing out all the fluids downstream of the shut-off valves, *i.e.* by purging the engine. In the first Black Knight flights, separation was achieved mainly by separating springs, but the impulse thus given proved to be insufficient and bodies were impacting again with the heads after separation; this sometimes caused minor, though nevertheless annoying damage. For later flights, we have both increased the separation impulse and have applied toppling moments on the body by firing small sideways-firing solid rockets and have obtained perfect separations. Fig. 18 illustrates the theoretical separation distances with and without taking account of the measured thrust dribble for the separation of the second stage.

If the second effect (*b*) is an important consideration this really causes a limitation to be placed on the means used to deal with effect (*a*), in that the smaller the impulse that is put on the separation payload the more accurately the separation velocity can be predicted or measured. If no separation is intended, then the integrated thrust dribble has to be accepted with or without purging of the thrust chamber.

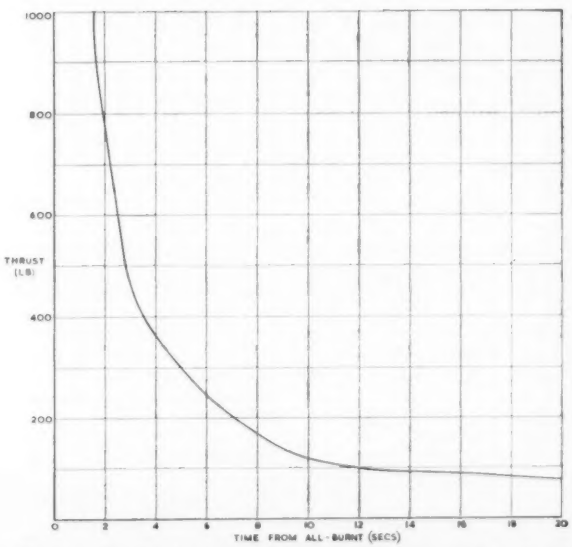


FIGURE 17. Typical acceleration fall-off converted to thrust.

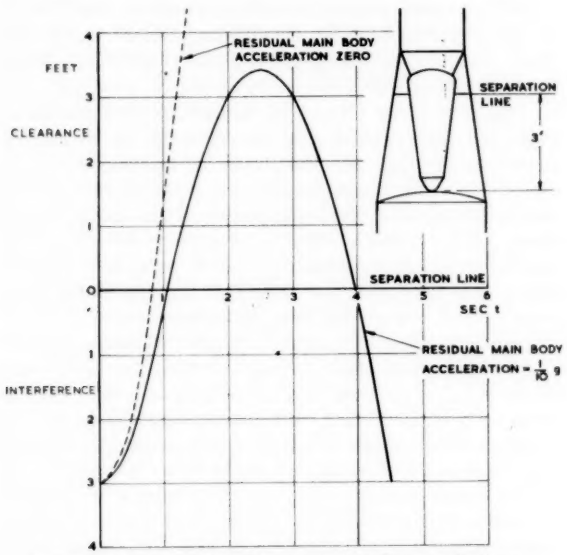


FIGURE 18. Separation of second stage from main stage.

6.4. KINETIC HEATING DURING BOOST

The kinetic heating problem is very well known but, particularly in the case of the ballistic rocket, the precise definition of the problem is difficult because of the uncertainties of the flow conditions (*e.g.* when is it laminar or turbulent) and the effect of the very low ambient pressures. The design of the Black Knight in this respect was made conservative by assuming that the Reynolds number at transition from laminar to turbulent was 1×10^6. Temperature measurements on the single-stage configuration (Figs. 19(*a*) and (*b*)) have shown, however, that laminar flow is held to a much greater Reynolds number than suspected, up to 20×10^6. Since the temperature of the missile skins has a significant effect in determining their ability to stand the imposed stresses, it is important to define this temperature as accurately as possible in order to minimise the structural weight. It would be unwise to assume that the high value of the transition Reynolds number obtained on Black Knight is directly applicable to all configurations, much more must be known about the effects of surface condition and of shape (including sharp changes of section) and tests often involve the real conditions of flight.

6.5. RE-ENTRY

I am not going to deal at length with the varied problems of re-entry, but as has already been said the last six Black Knights have all carried re-entry heads. These flights have been invaluable in assessing the value of ground test facilities, such as rocket motor sites, plasma-jets, shock tubes and so on, and theoretical calculations, in forecasting the performance of re-entry heads, particularly in the areas of heat transfer, ablation and dynamic motion. The satisfactory re-entry of the Black Knight heads has demonstrated the general success of the predictions, but much detail and simplification of methods of prediction remains to be done. I would like to draw attention again, however, to the interesting area of re-entry head radiations raised at the 10th International Astronautical Congress in London in 1959. Each of the Black Knight re-entries has been accompanied by large radiations over the visible spectrum as illustrated by Woodbridge at that meeting. The first stage body always gives the greatest light output due both to its size and the burning of the aluminium alloy used in its construction. The re-entry heads and the Cuckoo boost have also given out a large light output from up to 50–60 m. altitude down to very low altitudes, despite the fact that in many cases no material has been lost at all from the re-entry bodies; in these latter cases all the light output must be due basically to the ionised sheath around the body and in the wake, though the output is much larger in magnitude than forecasted by our original calculations. Fig. 20 shows a record from the re-entry of our successful two-stage round taken from a Baker-Nunn wide aperture, long focal length camera; the sideways steps on the light traces, seen also in the star traces, are the result of deliberate azimuth movements of the camera made to

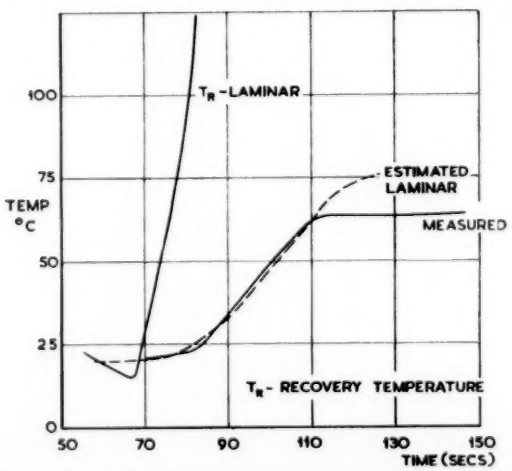


FIGURE 19(*a*). Instrumentation compartment skin temperature.

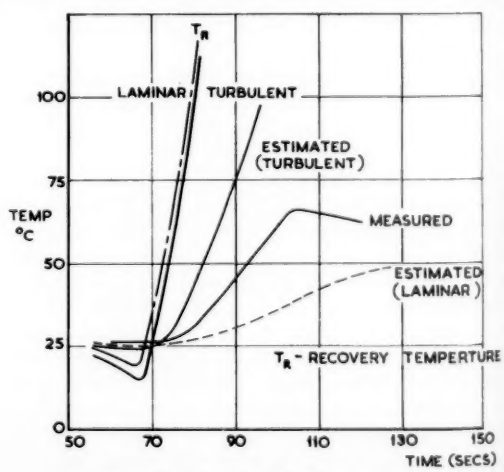


FIGURE 19(*b*). Inter-tank bay skin temperature.

separate out momentarily, the traces of different bodies (such as the Cuckoo boost and the head) coming in on almost the same re-entry track but at different times. The very bright trail at the left, is the track of the first stage body starting at a lower maximum altitude due to its lower velocity; the other partially superimposed trails on the right are the tracks of the head, the Cuckoo and a part of the second stage separated off during re-entry; the large spot at the top of these trails is the image of a flash ejected to mark the Cuckoo ignition at about 65 miles altitude. The hazy curtain-like image below the ignition point arises from a slowly decaying chemiluminescence of the atmosphere at this altitude which has been excited by the solid motor exhaust. This excitation can also be observed when pyrotechnic flares are ejected in the same altitude band.

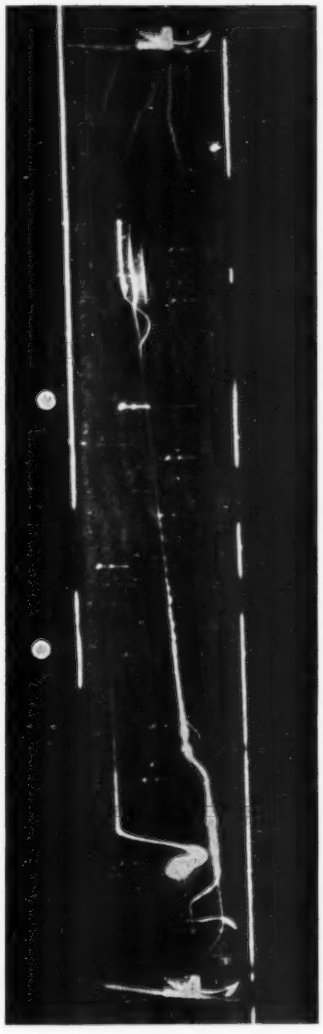


FIGURE 20. Baker-Nunn re-entry.

Much experimentation is still needed in this area of research, an appreciable proportion of which will have to be done in flight.

7. Concluding Remarks

In this paper I have attempted to show the role of ballistic research rocket and how it is related to the problems for which we use it as a research tool. The research flights with Black Knight continue to give us information on space environment and the problems concerned with the general advancement of the design of ballistic rockets including, as a most important group, satellite launching rockets. Although I have not dealt with the design of satellites themselves as they are outside the scope of this paper, it is relevant to note that the final proving of systems for, or examples of the satellites themselves, will often be done on a research rocket such as Black Knight before committing them to the very expensive satellite launchers.

Since re-use is not possible with Black Knight, it has to be remembered that each firing represents a not inconsiderable expense, and care should be taken to make each firing give worthwhile results. It follows that the correct role of such a rocket should be confined to limited exploratory exercises, to flights confirming vital points of the overall situation deduced from ground experiments and theory, and to investigations of effects which can only be properly experienced during a genuine flight test. I believe that there are very few areas falling completely into the third category. So the ballistic research rocket should be regarded as one of the tools in the tool-box, with the other tools, such as wind tunnels, engine test facilities, structural laboratories and so on, all forming necessary and integral parts of the research attack.

In conclusion, I should like to acknowledge the contributions given by Mr. H. G. R. Robinson and many others in R.A.E., the Saunders-Roe Division of the Westland Aircraft Co., the Bristol Siddeley Engine Co. and the Trials Staff of de Havilland Propellers Ltd. in the development of the Black Knight Rocket.

DISCUSSION

A. V. Cleaver (Chief Engineer, Rocket Propulsion, Rolls-Royce Ltd., *Fellow*): He would like to congratulate Mr. Lyons on the range of subjects covered. In view of that, perhaps it was a little ungrateful to ask for something on just one more topic that Mr. Lyons did not touch on, and that was the way in which the Black Knight project had been run. Mr. Lyons was obviously the right man to do this, since he came from the R.A.E. He thought everyone appreciated that basically the Black Knight was an R.A.E. project, although Mr. Lyons did refer to the work of Bristol Siddeley in developing the engines and of Saunders-Roe in developing the airframe. It would have been interesting to hear about the way the project had been co-ordinated, and the relative parts that had been played by the Ministry Establishment and the two firms mentioned, in connection with the propulsion and the airframe. The point he was emphasising was the way in which a Government team and two industrial teams—in fact he was sure many industrial teams in other components—had collaborated together to produce this extremely successful project.

There had been eight Black Knights fired, all launches had been successful and this was, at this stage of the art, quite an outstanding achievement in the development of advanced and complicated rocket vehicles. Could Mr. Lyons suggest any reasons for this. It was particularly important to this country—since they had not much money to spend, they must spend it as wisely as they could. If they could do it as well as this then perhaps they could afford it after all.

Mr. Lyons had mentioned something that the average man-in-the-street in this country did not appreciate, and that was that every one of the Black Knight flights had not been

literally one hundred per cent successful—he had referred to one or two troubles that were experienced. He was not drawing attention to this with the slightest intention of denigrating the achievement but it was worth noting that everything did not go quite according to plan. The troubles that were encountered in some of the flights had been overcome in the later ones, and that in itself was a tribute to all the people concerned in the project. Nevertheless, even if one allowed for these semi-failures—the first missile that was destroyed in flight before it was intended to be, the other one that finished the flight operating on three chambers, and things like that—even if allowances were made for these, the performance was quite outstandingly successful and it would be interesting to analyse the reasons why. He thought part of the reason was because the project, although fairly sophisticated, fairly advanced and complicated, was relatively small, and this always helped in some way that was difficult to define, in making a project easier. The test facilities used were more manageable, they were not quite so large, and this contributed to the success of the project. The other thing was that they did not try to do too much in too short a time. The time scale was creditably short, but it was not quite such a "crash" programme as some their American friends had been involved in. There was no attempt to fire quite so many missiles in this time and, by taking things a little more easily, perhaps success was a little more assured. He would like to know what the lecturer had to say, and whether he could suggest other reasons as to why Black Knight had worked so well.

Mr. Lyons: It was difficult to answer this question in a really convincing manner although they did try to organise themselves in the best possible way and by themselves he meant the teams both in the Government and Industry. He thought possibly the most positive thing they did was in fact to not control by committee and he was sure that the Aircraft Industry appreciated this. They tried to make one man responsible for the decisions with a proper pyramid under him. This one man within the limits of his brief could really take all the decisions, both financial and technical. This worked so well, he did not think they really knew in the whole team who was a Government man and who was in the Industry. He thought this probably did more than anything to make sure there was not any passing of responsibility about and everybody tried to play his part in the job. The other thing that the questions had drawn attention to, the fact that when in doubt they did not fire; they made very sure that when things looked as if they were going wrong, they did not press on just to see what happened, they tried to resolve the problem before they got too far. Now of course they must all recognise this was much easier to do in a research programme than it was in a military programme. They were the executors, they were the customers, they decided what was done and they bought the finished article. Now, in a weapon project or in an aeroplane project which was being made for somebody else, one always had the customers saying "You said the firing was going to be then, or the flight was going to be then and why are you late?" This pushed one a bit hurriedly along the development path and he thought quite a lot of their success was due to the absence of this direct pressure. He was sure that there were no abnormal mortals on the job at all, and they were able to contain the development work on the programme within their normal surveyable knowledge. It was a very real point that with a project the size of Black Knight, one did not need a superman to run it, but as the project got larger then one wanted someone correspondingly of greater ability to run it. A small project did run more smoothly and it was easier for one man to know everything that was going on in the project and thus easier for him to make decisions. In a large project it was difficult to know everything going on apart from the sheer load of organising the work.

R. C. Barker (Hypersonic Research Section, Bristol Siddeley Engines Ltd.): A number of people in this country and in the United States were working on propulsion units and vehicles for continuous flight in the atmosphere at hypersonic Mach numbers. To gain experience under these conditions the research facilities had grown from conventional wind tunnels into short-duration-running-time tunnels which could not simultaneously simulate the exact conditions of continuous hypersonic flight.

He would like to have Mr. Lyons' comments on the use of ballistic research rockets as a means of gaining data for investigations into hypersonic flight. Mr. Lyons had mentioned velocities between 9,000 ft./sec. and 16,000 ft./sec., and altitudes up to several hundreds of miles. Now, he believed that over certain altitude ranges one could simulate quite effectively such parameters as full-scale Reynolds number and stagnation enthalpy. Did Mr. Lyons think it was possible to use this area to explore hypersonic flight by the use of research rockets?

Mr. Lyons: Well, basically if one were going to employ air breathers, of course, the one thing that must be done was to keep the air breather in the place where there was air. This meant of course that the ballistic missile had got to change its role. The research rocket such as Black Knight was usually fired vertically upwards and was out of the atmosphere before the dynamic head reached a high value; therefore, to use this kind of vehicle in the way suggested, one would have to turn the flight path over early and fly more or less horizontally. There was no real impediment in the way of doing this apart from the normal troubles they had with range boundaries. Of course, in Australia in particular, the range was very long and they could readily turn over a missile flight path early and fly it down range, but he thought the most difficult thing to solve would be the guidance problem. Vehicles at this speed, unless they were properly kept under guidance and control would endanger any range boundaries—they could get such a very long way on their kinetic energy alone. They would really have to examine the guidance problem and probably put in a much more complicated one than the simple one they were able to use in the Black Knight. It was not out of the question, but one was really using the missile as a boost and then using its rocket thrust to keep it up at the correct level of altitude while one was doing the air breathing tests. But, of course, it depended what problem one was trying to examine; if one were looking at the engine problem he thought this was quite a reasonable suggestion; if one were trying to look at the aerodynamic problem he was not really sure that this was the best way to do it. As an alternative one could pitch over the booster missile and fire an aerodynamic test projected off the booster and investigate the hypersonic problems on the projectile, but he thought this was probably a clumsy way of doing it. So he would agree that it would be sensible to look at the engine problems of air breathers in this way but the hypersonic aerodynamics in other ways.

J. E. P. Dunning (Director, R. P. E. Westcott, *Fellow*): He would like to couple himself with what Mr. Cleaver said and offer his congratulations to Mr. Lyons for an excellent exposition. Although he had been acquainted with the Black Knight project almost from its beginning, he had learnt much that evening and, in particular, found Mr. Lyon's description of the illumination effects most interesting. By certain standards Black Knight was not a large vehicle, but even so its development was a major undertaking and the fact that it could be broken down into a number of components had, he was sure, contributed to its success. If each component could be developed in its own right and reach a high state of reliability, then in piecing them together one was already well on the way to making the complete job reasonably reliable.

It was five years ago that day that he went to Westcott and at the time had grave doubts about the selection of the propellents for Black Knight because of their comparatively low specific impulse. Now, however, he felt certain that the general characteristics of these propellents had contributed greatly towards success. In this particular context the propellents might be regarded as storable and this did reduce the general handling problems on the launching

site. Because the H.T.P.:kerosine ratio was about 8:1, the arrangement for the H.T.P. tank to exhaust first did ensure good propellent utilisation and this was an important advantage.

Mr. Cleaver stated that the success of Black Knight was because of the excellent co-operation between all the teams and in this Mr. Lyons had played a major part. In what had been achieved by Mr. Lyons and his team, Saunders-Roe and Bristol Siddeley, they were already well on the way to finding a rider on Blue Streak.

Mr. Lyons: On this question of reliability and of breaking up the missile into sections for development, he was not quite sure that he fully understood what was intended. He thought that whenever one was developing a missile, it had to be broken up into sections and one had to give each part to a team or part of a team to develop; but the point he was trying to make when he answered Mr. Cleaver was in fact that that was all right provided one kept control over each part while it was being developed —the only time it did not matter whether one had got control or not was when one had to buy the item off the shelf and one could turn it down or have it on its ensuing performance. Difficulty arose when somebody out of one's control was developing something for one, due to the matching of this part with neighbouring parts and due to the difficulty of foreseeing the specification in its broadest sense when one was starting a project of this kind; one needed to keep, in fact, a fluid specification, developing as the project was developing. If Mr. Dunning meant on the other hand the testing of the components properly before one ever put them into operation, this he agreed was absolutely vital. Before they flew anything on Black Knight, they did, in fact, do the most rigourous environmental tests to make sure that nothing would fail; they only slightly slipped up on this in one example of failure he told them about; that was in the transponder which gave the false cut down signal in the first Black Knight. But apart from that they had no breakdown of any major electronic part of Black Knight; none of their telemetering systems had ever broken down in flight at all and they had, in fact, fired a large number of them. On the propellant issue, he thought their choice had been a considerable easement in the design of Black Knight apart from the fact that the propellants had a reasonable S.I. He did not think it was so much the storability that had helped so much as the fact that the handling of them was easy, and he meant this in the broadest sense, including the design of pumps and valves and pipes and the fact that neither propellant was very cold. He did not mean to imply that one should not use a propellant which was cold; one could design against cold, but if one were trying to develop a research tool then perhaps there was no need to do unnecessarily hard jobs. It certainly helped in the time scale, and in getting something successful quickly, that the propellants were not either very cold, and caused complication in design of both structure and pipes, valves and so on or very corrosive like nitric acid or liquid fluorine. Again, he was not saying that one should not use them in particular applications but it certainly did help not to have them unless one needed them really badly. He thought another point was made on the possibilities of these propellants for space launchers. Of course, the rather low S.I. was quite a debit on a space launcher, but his criterion was, would it do the job or not, and in the sort of proposals they had made which included one of these propellants they were able to give the sort of payloads they wanted in the orbit they desired. But there was one point about H.T.P. which was useful in this application and it was that it did considerably ease the separation problems of liquid stages. They could, in fact, start up Black Knight in flight assuming it had been boosted from the ground say as a space vehicle launcher, by allowing H.T.P. from a pressurised source to be pushed through the catalyst pack; the engine then immediately started to run in what was called "cold-running." This, in fact, meant that while the stage was in the proximity of the first stage or the previous stage, one was not risking damage to the previous stages which in turn might inflict damage back on the stage that one wanted to go on. In other words, if one directed a cold H.T.P. steam jet from the back of the second stage onto the Blue Streak used as a first stage, then one probably was running little danger of damaging the Blue Streak and causing it to blow up thus causing a major catastrophe. When the stage was well away kerosine could be turned on and the full S.I. obtained. This was quite an advantage and in addition it made the liquid stage much more akin to solid stages which in this respect were easy to start up in space conditions.

Dr. Moult: He would like to compliment Mr. Lyons not only on an excellent lecture but on the vast amount of work he had done personally in furthering the various projects, Black Knight in particular.

Missiles were missiles, but there was a growing awareness to the more pacific uses of artficial satellites which could be launched successfully by rockets of the type described. A number of members of the Society had recently attended a lecture at the Institution of Electrical Engineers devoted to the use of satellites as an aid to communications. There were possibilities of world-wide radio communications at cheap rates, independent of atmospheric interference. Ultimately, there could be world-wide television on aircraft and on ships at sea: whether this was regarded as an advantage or otherwise was a matter of personal choice! In all directions they were on the threshold of tremendous developments and it was for the younger engineers to bring these possibilities to fruition.

He would ask Mr. Henry Gardner, Member of Council, to propose a formal vote of thanks.

Mr. Henry H. Gardner: It was a great pleasure to give the vote of thanks. He would first like to thank Mr. Pollicutt for the welcome he gave to the Branches; it was indeed a pleasure to see so many senior people from so many Branches present.

He would like to congratulate Mr. Lyons on his Lecture. Had he chosen to give a sermon and taken as his text "The art of co-operation" or "The art of getting together" the material he had used that evening would, in fact, have been equally suitable. He would also like to compliment Joe Lyons on his modesty. He spoke of one man who was in charge of the project—he did not tell them that that man was Mr. Lyons himself.

The R.A.E. were notoriously famous for their ability to produce lectures and Mr. Lyons had given an example of the R.A.E. lecture at its best. He had taken a difficult subject and dealt with the actual events, he had avoided what must have been a great temptation, to talk about space, space flight and satellites, and he had really confined the discuscussion to the actual job. He would like to congratulate him not only on his excellent lecture, but on the way he had put it over.

This art of togetherness, he thought, had been clearly demonstrated by Mr. Lyons' team. He thought it was quite true to say that the project had gone much better than anyone would have predicted. If at any time they had wondered what was the magic behind it then the lecture tonight had made this clear. He felt that Mr. Lyons had demonstrated one of those old very simple axioms of the aircraft industry, *i.e.* "Simplify and add lightness." The lecture had proved the old saying in a new form, that was "Simplify and add reliability." That had been done in Black Knight and had been demonstrated that night.

If he might just have a word on Sections of the Royal Aeronautical Society, he thought it was quite significant and important that the Astronautics and Guided Flight Section, which was now becoming almost elderly in the Section history of the Society, was the first one to be formed. It was, in fact, started some two or three years ago, when the name to be adopted by the Section presented a serious problem for the Aeronautical Society. There was a good deal of support for the name "Rocket Section," and the advocates of this name put up a worthy struggle. After listening to Mr. Lyons tonight the doubts he felt when the present name was adopted had all come back and one wondered if the right decision was taken.

On their behalf, he would propose a hearty vote of thanks to the lecturer, who had given them a splendid lecture.

The Royal Aeronautical Society
The First Fifty Years—1866 and All That

BY

J. LAURENCE PRITCHARD, C.B.E., Hon.F.R.Ae.S., Hon.F.I.A.S.

Captain Pritchard has been carrying out research in aeronautical history since his retirement. Many of his papers have been published in the JOURNAL and they have thrown new light on the Society's history and the work of some of its members.

His researches have revealed many missing gaps and it is hoped that the publication of these abstracts from his fuller history of the Society may encourage members to contribute to the history from their own knowledge. The Society is now nearing the centenary of its foundation in 1866, and much hidden away in family archives of aviation history still remains to be revealed. It is hoped that these abstracts, to be published over the following months, will help in writing the history of the oldest and greatest Aeronautical Society in the world.—ED.

" He has half the deed done, who has made a beginning."
Horace, Epistles, Book 1.

THE YEAR 1866

" God bless the Duke of Argyll!"

In the Lecture Hall at Hamilton Place, London, of the oldest aeronautical society in the world, that Duke of Argyll, who became its first President in 1866, looks silently down upon those members who, less than a century later, succeeded so noisily to fly faster than the sounds of their own triumphant cries of success.

Some, who approach the painting of the Duke to read the inscription and so learn his identity, exclaim " God bless the Duke of Argyll!" Others, aware of the significance of the phrase, turn away silently.

The ancestor of that Duke whose name is written first in the lists of Council of the Society, erected a row of posts to mark his property. These posts were used by his gillies as back-scratching posts, awhile they exclaimed " God bless the Duke of Argyll!" The art of back scratching has been subtly revived in this twentieth century for other kinds of posts.

Which particular Duke of Argyll put up the back-scratching posts is not the province of this history to record. We are concerned, very much concerned, with the eighth Duke, who was born in 1823, who succeeded his father in 1847, and became Lord Privy Seal in 1852; Postmaster-General in 1855; President of the British Association for the Advancement of Science in 1855; President of the Aeronautical Society of Great Britain in 1866; Secretary of State for India in 1868, the year the Society held the first aeronautical exhibition in the world; whose son married the Princess Louise, the fourth daughter of Queen Victoria; and who died in 1900.

Any Society, in any blandiloquent capitalistic State, might well have thought itself fortunate to begin life with such a figurehead, but the Aeronautical Society of Great Britain was more fortunate than in just having a Duke to give lustre to its Council list. The eighth Duke was well-known as an author with an ordered and scientific mind, and one who had made a special study, following in the aerial highways of the avian seventh Duke, of the flight of birds. He was also a Fellow of the Royal Society.

Indeed, in the very year before he became President of the Society, he published a book which was to become famous, *The Reign of Law*. Chapter 3 is a dissertation on the machinery of flight which might be read with some untaxed profit by many even today. The last words of the chapter are prophetic:—

" When Science shall have discovered some moving power greatly lighter than any we yet know, in all probability the problem will be solved. But of one thing we may be sure, that if man is ever destined to navigate the air, it will be in machines formed in strict obedience to the mechanical laws which have been employed by the Creator for the same purpose in flying animals."

The Duke of Argyll was the President of the British Association when it held its meeting in Glasgow in 1855. He continued to be a member and when it met in Birmingham in September 1865 it is significant that among those on the roll of the Association for that year were Sir Charles Bright, William Fairbairn, James Glaisher, and the Duke of Sutherland, all of whom agreed to serve on the first Council of the Aeronautical Society in the following year. Indeed out of the fifteen members of Council listed at the beginning of the first Annual Report issued in 1867, no fewer than eight were members of the British Association in 1865.

In its annual report for 1865 there appeared among the transactions of the Association the following abstract of *Remarks upon Aerial Navigation suggested by Mr. Glaisher's late Balloon Ascents*, by F. W. Brearey.

" Mr. Brearey, alluding to the important observations of Mr. Glaisher, remarked that we had only been creeping along the borders of a vast immensity of which we know almost nothing.

" Now that public attention was directed to those scientific efforts, and that the balloon was becoming more than a toy, he would at once propose the formation of a Society, to be supported by subscriptions and donations, by which experiments could be conducted in its own grounds, and with its own apparatus, for the furtherance of investigations in aerology and aerial locomotion.

" After pointing out the requirements of aeronauts for locomotive purposes, Mr. Brearey suggested, with the object of saving gas and ballast, that a man might *raise himself* in the air by a mechanical appliance attached to a balloon inflated only to such an extent as would give him buoyancy. The downward blow of paddles made of bamboo and silk, if returning feathered for each succeeding stroke, would enable him to effect this, and also to keep a low elevation, go with the wind, ascend and descend at pleasure, find different currents, and save gas for future use.

" It would, moreover, comply with the conditions insisted upon by late writers on aeronautics, viz. ' that

to contend with the air, one must be specifically heavier than the air.' "

In a statement read at the second council meeting of the Society, held on 28th February 1866, and afterwards issued as a four page pamphlet, he remarked " Impressed greatly with the belief that holding moderate views, an Aeronautical Society would be supported even by those who had made all preceeding attempts a subject of ridicule, I went down to Birmingham, by the advice of Mr. Glaisher, to make certain simple suggestions, at the meeting of the British Association, and at that meeting the nucleus of the Society was formed."

It was Glaisher himself, at the first meeting of the Council on that historic 12th January 1866, who played the decisive part which brought about the agreement to found the Society. He was speaking to men who were scientists and engineers, men who were not easily swayed by enthusiasm alone.

There were present at the meeting, the Duke of Argyll; James Glaisher, a Fellow of the Royal Society who had been carrying out meteorological research in a balloon for the British Association, and was a founder member and secretary of the Meteorological Society; Francis Herbert Wenham, a well-known engine designer and a remarkable designer of scientific instruments and microscopes; James William Butler, who lived to meet and to have lunch with the Wright Brothers on the occasion of their visit to London in May 1909; and Hugh W. Diamond, a doctor long interested in air matters, and secretary of the London Photographic Society; and F. W. Brearey, who became the Honorary Secretary for the next 30 years.

The meeting was held at Argyll Lodge, Hampden Hill, the London House of the Duke of Argyll. Glaisher gave an address to those present in which he said, " It is confidently hoped that by the organisation of the Aeronautical Society of Great Britain ' the subject may take its standing among the sciences.

" Information is much needed concerning the direction of varying currents of air in the upper and lower regions of the atmosphere," he added, and " A chief branch of inquiry by the Society would be the department relating to the mechanical expedients and inventions for facilitating aerial navigation, and obtaining or aiding a change of locality at the will of the aeronaut."

Glaisher finished his address with the words, " When we consider that the act of flying is not a vital condition, but purely a mechanical action and that the animal creation furnishes us with models of every size and form, both single and compound wings . . . . . it seems remarkable that no correct demonstration has ever been given of the combined principles upon which flight is performed, nor of the absolute force required to maintain that flight. In the absence of an established principle, much time and money has been wasted in attempts to adapt aerial propellers, and it would be the office of the Society to bring forward any information or experiment illustrative of a theory; and with the aid of the eminent mechanicians and men of science that the Society may reasonably expect to number among its members, a fair hope may be entertained that this way may be accomplished."

Although the reasonable expectations have been amply fulfilled and the Society, in the course of its long existence, has numbered among its members the most eminent mechanicians and men of science, none of those present at the meeting could have foreseen how narrow, indeed, was the margin between expectation and accomplishment. But for the enthusiasm of Brearey, its first secretary, and Glaisher, its first honorary treasurer, the Society itself would not have survived.

Brearey was then in his fiftieth year and his ideas were to some extent fixed. He had, however, the important virtues required for the true pioneering spirit, the one-track mind and a great confidence, despite his lack of any kind of technical knowledge, that what he was doing would be for the benefit of mankind. He hypnotised himself, indeed, in later years into the belief that he had discovered the secret of flying, when men of great scientific and engineering ability around him had failed.

But whatever may be said about Brearey in later pages, and I shall have much to say about him in one way or another, it must ever be remembered by those who cherish the Society and its aeronautical traditions, that if it had not been for Brearey the Royal Aeronautical Society would not have had the unique record it now possesses. He served the Society faithfully for its own glory as well as his own.

At the Council meeting held on 28th February 1866, he read a statement which was not reported in the Council minutes nor in the Annual Reports, but was printed as a four-page pamphlet. It is now one of the rarities of aviation literature.

" In the formation of the Society," said Brearey, " I had the simplest object in mind, feeling that although the time was favourable for movement, it was not safe to encourage the idea that any extravagant notions were contemplated. Indeed, I hold the opinion that much will be accomplished, and that the pleasure and gratitude of mankind is on the eve of being greatly enhanced."

At the preliminary meeting on 12th January, the following resolution was proposed and agreed to by the six pioneers at Argyll Lodge:—

" Resolved that it is desirable to form a Society for the purpose of increasing by experiment and knowledge of aeronautics, and for other purposes incidental thereto, and that the Society be now formed under the title of the Aeronautical Society of Great Britain, to be supported by annual subscriptions and donations."

The Council was self-appointed and autocratic. Under the rules the members of the Society had no power over their Council and no real say in the affairs of the Society. They could only signify their disagreement with the Council's policy by resigning or not paying their subscription (and under the rules the Council could expel them!). As long as that membership consisted of hopeful enthusiasts eager for any opportunity to get together and talk and publish what information was available, this was probably the only way the Society could exist. The membership was small and could not afford a paid secretary. Indeed, at the end of its first year the paying membership was only 41.

But be it remembered that these men who agreed to form the first Council of the Society did so at a time when the great majority of scientists and engineers looked upon the possibility of flight as purely visionary. But they were men of standing in their own spheres of activity, and their vision extended to the distant horizons of successful achievement, even if it did not come in their own lifetimes.

At the Council meeting held on 17th April, Mr. Butler, who had been paying a visit to Paris, gave some interesting facts to the Council as to the progress of

aeronautics in France. Arising from what he had to say, a discussion arose as to the feasibility of an Exhibition in London to illustrate methods of ascending into the atmosphere without the aid of balloons. It was agreed that Butler should talk the suggestion over with the French, so that any inventions of both countries might be collected in one Exhibition. The Council were more optimistic in this respect than they should have been. It was not until 1868 that any kind of Exhibition could be held, and then it was damned with faint praise by the French!

It was agreed at this meeting that the first experiments under the auspices of the Society should take place the following month, by Mr. Glaisher, from a balloon owned by a fellow member of Council, Mr. Westcar. The Council were setting an excellent example to their members. It was agreed that some experiments especially adapted for a consideration of a theory of flight of birds should be attempted from the car of the balloon.

The Minutes do not record what the experiments actually were. Nor is there anything recorded in the *Annual Report*. A contemporary account of the balloon voyage in the *Mechanics Magazine* reported, " An ascent was made on behalf of the Society from Windsor by two of the Council, Mr. Glaisher and Mr. Westcar . . . . . Mr. Glaisher took the opportunity of conducting some investigations for the British Association; and Mr. Fred Brearey, Hon. Secretary of the Society, attended with some models presented by Mr. Wenham, to detach from the car of the balloon at a height of about half a mile, in illustration of the flight of birds."

It is interesting to compare the points of view of the two occupants of the balloon. The ascent was made on 29th May 1866. Glaisher was busy during the whole voyage recording readings from his instruments. Westcar confined his attention to the voyage as a source of pleasure. " The ascent was one of great interest," he wrote, " in as much as it occurred at Ascot race time, and we had a perfect view of the Course before, during and after the last race was over; and, as far as my knowledge goes, it is the first time that a race has been witnessed from a balloon.

" What struck me most forcibly during the ascent," he added, " was the accurate and plain way in which Mr. Glaisher read off his instruments, which were all so delicately protected . . . . . but even above that, the simple yet effective way that these instruments were packed and put away the instant they were done with. This can only be imagined when I say that out of all these delicate thermometers, etc. not one was broken or put out of order, although Mr. Glaisher's hat, which was certainly a good one before the ascent, afterwards resembled a mere mass of black felt and brown paper, having dropped under the car as we came down!"

The Councils of the Society, before 1914 at any rate, were more cosmopolitan than they have been since the aeroplane has become too successful (in the estimation of other forms of transport).

Eleven meetings of Council were held in the first year. At the second meeting, on 12th February 1866, with the Duke of Sutherland in the Chair, Brearey reported that in reply to his request, the Commissioners of Patents had made a gift to the Society of all aeronautical patents, " commencing with the year 1617."

The seventeenth century date was two hundred years too early. The actual patents began with one in 1815, the second one being dated 1843. From then to this present year the little patents have hurried up and more and more and more, all eager just to show the world how to fly and soar. These patents, in the possession of the Society, form one of the most comprehensive collections of aeronautical imagination in the world. They give indeed, an imaginative picture which even Picasso would have envied if he had been an aeronaut.

Among the members elected at the second meeting of the Council was Paul Haulein, who put forward to the Council an account of his proposals for an airship. A German engineer, he is credited with being the first man in his country to build and fly an airship, in 1872. He had taken out a British Patent in 1865.

He proposed an ellipsoid as the best shape, driven by a gas-heated steam engine, provided with an ingenious cooling apparatus, " the power of which is sufficient to cool in the same time the same quantity of water which the engine heats." Three propellers were provided, two for horizontal and one for vertical movement of the airship. Haulein provided an inner balloon which could be filled with air to any extent required. The excess gas from the balloon served as fuel for the gas jets. The horizontal propeller enabled the airship to change its altitude without being forced to discharge gas or water in the form of ballast.

At the Council meeting the President suggested that the Society should approach the British Museum to set aside a room for the reception of models " for aerial navigation." Nothing more was heard of the suggestion, however, and it was not for many years later that the still inadequate and badly housed aeronautical exhibit appeared in the British Museum.

The President also suggested the publication of a regular Journal of the Society. The suggestion was not fully carried out until after the death of Brearey thirty years later. In place of a regular Journal, the *Annual Reports* of the Society's activities were published from 1867 to 1894. These *Annual Reports* edited and prepared by Brearey, with the help of Wenham, form an aeronautical record without parallel in any part of the world. In them lives the vital enthusiasm of those early members of the Society, an enthusiasm which every modern member has only to emulate to keep the oldest Aeronautical Society in the world the youngest in spirit and endeavour.

A second meeting of the Council was held in that month to consider, among other things, " the best mode of increasing the strength of the Society." Those were the days when membership could only be counted in tens and it was suggested that canvassers should be employed and paid 12½ per cent on the first year's subscription of a member, or on any donation they might obtain.

At this meeting Glaisher agreed to pay all the expenses of circulating Brearey's address to some 750 members of other Societies and 200 copies to newspapers in the United Kingdom. This generous offer of help to the Society at the very beginning of its existence, was an example which has been followed by many members of Council since.

The first annual subscriptions were fixed at one guinea, and remained at this sum for thirty years.

At the Council meeting held on 23rd May, a letter was read from the President of the Aerostatic and Meteorological Society of France, desiring a joint co-operation for the attainment of the objects contemplated by the two societies, a desire to which the Council readily agreed. It was the first co-operation between two aeronautical bodies in the world. It was at this

meeting that it was announced that the Duke of Sutherland offered a prize of £100 to anyone who could, by mechanical means, fly from the garden or from Green Park to the top of Stafford House, a prize for which there were no entries, but one which could be won today with much ease.

It was not until the end of the following month, on 27th June 1866, that the first lecture was given before the members of the Society in the Great Hall of the Society of Arts, which had been founded nearly a hundred years before. In that Great Hall there were to speak most of the distinguished figures in the Aeronautical Society for the first seventy years, from the Duke of Argyll to those present-day leaders in aeronautical science and industry.

From 1866 until 1935, when larger audiences compelled a regretful change, the meetings of the Society were normally held in the Society of Arts rooms. The Aeronautical Society was so poor, its membership so small, that the Society of Arts made no charge in those early days, so that those whom the law sometimes threatened to lock up as lunatics, could talk about those mad days of the future when man would fly. It gave me great pleasure, personally, on the occasion of delivering the fiftieth Anniversary Lecture on The Work of the Wright Brothers in that historic hall on 16th December 1953, to be able to pay a long overdue public tribute to those kindly hosts who had befriended the struggling Aeronautical Society for so many impecunious years.

On 1st June 1866, Wenham wrote to the *Mechanics Magazine* " From the letters of your correspondents I see that the question of aerial navigation by mechanical means is seriously revived. I may state that the function of the Aeronautical Society has developed the fact, by communications received, that many are now of the opinion that man may yet command the air as a medium of transit in any direction."

Wenham discussed the mechanics of bird flight and the forces necessary to enable the humming bird to hover and the albatross to soar. His letter was a preliminary *ballon d'essai* to the paper he had agreed to read before the Society later in the month, a public statement of considerable importance to indicate the technical and serious outlook of the new Society. He described the power required for vertical and horizontal flight. " In the case of the albatross the power exerted during the easy and long sustained flight of the bird is probably about one thirtieth of that of the humming bird, considered relatively to weight. If this be correct, then the means of flight may be within our reach, not only with motive powers already known, but also by means of individual force."

Wenham had, like many other experimenters who followed him, overlooked the difficulty man had to apply all his power. I find it difficult to understand why Wenham did not discuss the possibilities of gliding flight.

" It is the province of the Aeronautical Society to collect all information, without putting forward any opinion, and to be the means of settling this long-vexed question, is flight possible for man?"

Francis Herbert Wenham had gained a high reputation as a marine engineer, in which profession he was trained by a Bristol firm. In the five years he served as an apprentice he obtained a mechanical insight which was to give him an enduring name in the history of aviation. He was forty-two when he delivered the first lecture before the Society, " On Aerial Locomotion by which heavy bodies impelled through the air are sustained." The lecture was subsequently published in the proceedings of many societies and in many papers and books concerned with flight. If any Society ever stepped off on the right foot, the Aeronautical Society did, however much it may have missed its footing on occasions since.

Before Wenham's lecture the President called upon the Honorary Secretary to give a brief outline to those present of the aims of the Society. Brearey began by making that classic statement, which has been made at frequent intervals about the lectures and papers published in the Society's Journal, " It is necessary to claim on behalf of the Council perfect immunity in respect of any complicity with the views of their respective authors. It cannot be too often repeated that the Council, as a body, has no theories of its own."

The cynic has remarked since, on more than one exasperated occasion, " the Council, as a body, has also no mind of its own."

Brearey added about the Society, " Its formation is due to the existence of some facts which cannot and ought not to be ignored. First, the almost universal desire common in all ages of the world and amongst all races of men, for obtaining more command over the comparatively unoccupied space which has continually eluded all attempts, although man observes that bodies possessed of weight command it almost without an effort."

Brearey drew attention to the importance of having an organisation like the Society because of the " constant recurrence of isolated attempts to triumph over some of the acknowledged difficulties of propulsion and navigation by inventors who, for want of organisation, are unacquainted with preceding failures in the same direction . . . . for by continuing to observe and to record, we shall progress towards that which is unknown."

There immediately followed Brearey's statement, Wenham's paper, largely prepared some seven years before the Society was founded, as the result of his observations on the flight of birds during a trip up the Nile.

" The sustaining power obtained in flight," he declared, " must depend upon certain laws of action and reaction between relative weights; the weight of a bird, balanced, or finding an abutment, against the fixed inertia of a far greater weight of air, continuously brought into action in a given time. This condition is secured, not by extensive surface, but by greater length of wing, which, in forward motion, takes a support upon a wide stratum of air, extending transversely to the line of direction."

Wenham added, " In all inclined surfaces, moving rapidly through the air, the whole sustaining power approaches towards the front edge," a fact already noted by Sir George Cayley sixty years before. He was convinced that a long, narrow fixed wing held out the best prospects of success, and that, from an engineering point of view, it would be necessary to have a multiplane.

" In order to test this idea, six bands of stiff paper, three feet long and three inches wide, were stretched at a slight upward angle, in a light rectangular frame, with an interval of three inches between them, the arrangement resembling an open Venetian blind. When this was held against a breeze, the lifting power was very great, and even by running with it in a calm it required much force to keep it down."

Wenham made a full-sized glider, " sufficient size to carry the weight of a man, consisting of five bands of holland, fifteen inches broad and sixteen feet long, the total length of the web being eight feet."

The holland webs were stretched between rods, and a central board and iron bands completed a braced structure.

" This was taken out after dark into a wet piece of meadow land one November evening," related Wenham, " during a strong breeze, wherein it became quite unmanageable. The wind acting upon the already tightly-stretched webs, their united pull caused the central boards to bend considerably, with a twisting vibratory motion . . . . A sudden gust caught up the experimenter, who was carried some distance from the ground, and the affair falling over sideways, broke up the right-hand set of webs."

Another and more elaborate machine was constructed with two foot-driven propellers, and this, in turn, was modified, but without success.

" It may be remarked," said Wenham in his lecture, after a detailed description of his experiments, " that although a principle is here defined, yet considerable difficulty is experienced in carrying theory into practice. When the wind approached fifteen or twenty miles per hour the lifting power of these arrangements is all that is requisite, and, by additional planes, can be increased to any extent; but the capricious nature of the ground currents is a perpetual source of trouble."

The significant thing about Wenham's analysis and experiments, which were not continued, is that he did not appear to have considered at all the stability of the apparatus he had designed. There was no suggestion of longitudinal or lateral control.

At a meeting of the Council held on 24th August 1866, the following significant resolution was passed:—

" It was delegated to the Duke of Argyll, Lord Dufferin, Mr. James Nasmyth, Mr. J. McConnel, Mr. Glaisher and Mr. Wenham, to consider the law of resistance of inclined surfaces moving in elastic and non-elastic fluids, as air and water, and the resultant force obtained at right angles to the direction of motion. Experiment has now proved that as the velocity is increased, and the angle of inclination diminished, the centre of effort of the plane approaches forward, till nearly the whole effect of reaction or support is transferred to the front edge. It therefore follows that in very acute angles with the line of motion, a given extent of reacting surface at high velocities will be the most effective if disposed in a narrow plane extended transversely to its direction. An investigation of this principle will determine the best ratio of surface to speed in the long and narrow wings of birds of extended flight; in the blades of reciprocating and screw propellers; and in the sails of vessels for sailing near the wind."

The Council of the Society were approaching, in their first year, the problem of flight in a scientific way and were trying to cut away the vast undergrowth of speculative theory and haphazard experiment, which for centuries had brought little but ridicule on all those who had attempted to solve the problem of flight. It was the first real effort to find the forces on a given surface at a given speed and varying angles of attack since Sir George Cayley had carried out such experiments over sixty years before.

The first Annual Report of the Society, under the title *Aerial Locomotion* was printed and published for the Society by Cassell, Petter and Galpin & Co., later better known as Cassells. The Council Minutes of 19th March 1867, record that Wenham and Brearey, acting on behalf of the Council, had ordered 1,000 copies, a large order for those days. Copies now are very scarce. In it a letter was printed, written over a year before, from an enthusiastic experimenter, F. D. Artingstall of Manchester, he explained he had made a number of ornithopter models driven by a small steam engine. The model engines usually burst, the wings refused to lift, and the models, held by a cord from the ceiling, " whirled round, rushed from side to side, and in fact performed all kinds of gymnastic movements within its limits (except flying!), to the great amusement of the particular friends invited to witness the experiment."

Artingstall was no passing dabbler in aeronautics. He had theories about the flow of air over the wings of birds and insects and had corresponded, many years before the formation of the Society, with Sir George Cayley. The *Annual Report* quite frankly stated that the Society had published the letter to show how much time and money was being wasted by those who tried to imitate birds.

In summing up the activities and hopes of the first year, it was stated by the Council that they were of the opinion that the balloon had not been sufficiently utilised and suggested there might be mechanical means for ascent and descent without the loss of gas or the use of ballast. The Council regretted how little had been accomplished to demonstrate the laws " upon which heavy bodies find support upon the air." They did recognise, however, that the greatest difficulty was the take-off and a suggestion was put forward for a light railway track to enable the aeroplane to reach the necessary take-off speed, the first suggestion for assisted take-off.

The Society received many suggestions from those who had seen the announcements of the new body, both from Britain and abroad. The Société Aérostatique et Météorolgique de France, founded the year before the Society, though destined not to survive so long, expressed a wish to keep in close touch with the new body and sent copies of its own annual reports for 1865 and 1866. A number of books were presented to the Society by members and others to provide a nucleus for the first aeronautical library, now the finest such library in the world.

Brearey kept a meticulous account of the income and expenditure of the Society for the years 1866-1870, in a small pocket account book which has fortunately been preserved. His obvious lack of knowledge of any method of bookkeeping, clothes these accounts with the flesh and blood of human interest which is so often lacking in modern mechanical accounting methods.

At the end of its first year the Society had a total membership of 65, of whom 41 were paying members and the rest honorary. The total receipts were £56 13s. 0d., of which over £13 were donations. The year's expenditure was £46 18s. 10d. James Glaisher was the Honorary Treasurer and F. H. Wenham the Honorary Auditor.

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TECHNICAL NOTES

A Note on the Vorticity Distribution on the Surface of Slender Delta Wings with Leading Edge Separation

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A DESCRIPTION is given of the distribution of vorticity in the surface of thin wings with large leading edge sweep. Although the delta wing is chosen as the basic plan form the deductions are general and applicable to other types of wing. The conclusions are illustrated with experimental evidence from a water tunnel.

1. INTRODUCTION

The flow pattern over and around a highly swept delta wing with sharp leading edges bears little resemblance to that predicted by simple "slender body" theory. It is dominated by a pair of spiral vortex cores above the wing formed by the rolling up of vortex sheets springing from the leading edges. These vortices are important because they produce substantial (non-linear) increments in the lift and drag and they alter the downwash pattern near the trailing edge considerably.

The theories available at present are cumbersome and not in very close agreement with experiment. They are all based on the "cross-flow" assumption and take no account of the existence of a trailing edge. To improve them it will probably be necessary to follow the classical pattern of replacing the wing and its wake by a distribution of vorticity, and to do this economically it is necessary to have some idea of the actual distribution. Therefore in this note an attempt is made to deduce qualitatively what the vorticity distribution in a wing with leading edge separation must be. No doubt it can be calculated from the existing theories but it is instructive to derive it without mathematics.

2. DESCRIPTION OF THE FLOW PATTERN

The vortex sheets at the leading edges arise in much the same way as that at the trailing edge of a conventional wing of finite span. If the edges are sharp enough they carry no load (equivalent to the Joukowski hypothesis) and vortex sheets are formed if the streamlines just outside the upper and lower surface boundary layers are in different directions at the edge. The vortex sheets roll up into a pair of conical spirals the centres or "cores" of which lie well inboard of the leading edge and above the wing surface. The rotation is inwards, *i.e.* in the same sense as a conventional trailing vortex pair.

The induced flow is towards the upper surface at which it divides and turns spanwise—inwards or outwards—and chordwise, *i.e.* parallel to the free stream direction. Beneath the vortices the induced flow is obviously spanwise outwards but between them the symmetry of the arrangement prevents much inward flow. The fluid therefore turns chordwise in this region. Now the vortices are quite strong and the spanwise outflow is of the order of the free stream velocity. Therefore, outboard of the lines on the upper surface where the induced flow divides the resultant velocity make a large angle with the free stream direction. Between these lines the flow is roughly in the free stream direction. Thus the dividing line is one from which streamlines diverge and is an attachment line, according to Maskell's[1] definition. This upper surface flow pattern has often been demonstrated by the "oil flow" technique. The lower surface flow has not aroused so much interest but Fig. 1, obtained in a water tunnel, shows that the flow is in the free stream direction over the inner part. There is an outwards flow near the leading edges but this is not nearly so marked as that on the upper surface.

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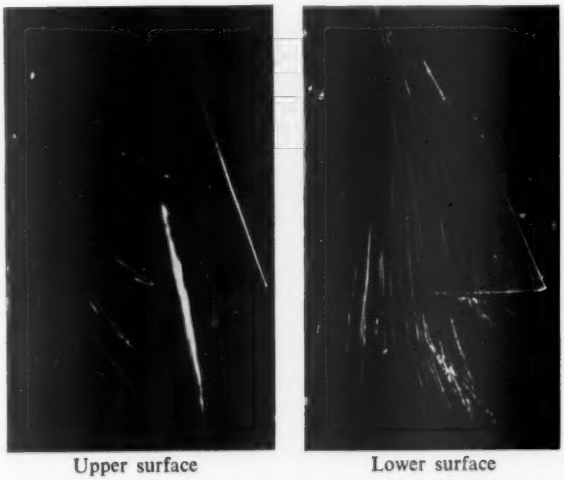
3. THE VORTICITY DISTRIBUTION

At any point of a wing surface the fluid velocities just outside the upper and lower surface boundary layers are different in both magnitude and direction. In the vortex sheet theory the velocity changes are assumed to take place discontinuously through a "bound" vortex sheet which has the same plan form and mean incidence as the wing. The differences in magnitude and direction of the velocities are represented by the strength of the sheet and the orientation of the vorticity vector. On a delta wing with leading edge separation the vorticity distribution is determined largely by the upper surface flow since the velocity variations there are much greater than on the lower surface.

A vortex sheet can be looked upon as a distribution of vortex lines, or contours of vorticity, which join points of equal strength and are everywhere tangential to and in the same direction as the vorticity vector. Looking along a vortex line the fluid always turns either clockwise or anti-clockwise about it. Points of equal strength but opposite rotation may then lie on the same line provided that it makes an obtuse-angled turn between the points. Vortex lines do not terminate abruptly at the wing edges but cross them to make up "free" vortex sheets which extend to infinity downstream of the wing.

The conditions which govern the distribution of vorticity



Upper surface Lower surface

FIGURE 1. Surface flow patterns on 70° delta wing at 26° incidence.

in vortex sheets have been discussed in a general manner by Kuchemann.[3] The load at any point of a vortex sheet is dependent upon the resultant of the velocities on opposite sides of the sheet and also upon the angle between the resultant vorticity and velocity vectors at that point. If a sheet separating regions of equal total head can sustain no load, *i.e.* a free vortex sheet, these two vectors must be parallel. This condition applies to wing edges (tip, swept or trailing) at which there is smooth outflow. In the case of sharp-edged wings which develop spiral leading edge sheets the vorticity vector at the edge must lie in the same direction as the resultant of the upper and lower surface velocities and will in general be inclined to the edge. Thus the vortex lines along the leading edges will appear to diverge outwards from the wing centre line and are inclined to the edges; the rotation is inwards.

If we consider any one vortex line entering the bound vortex sheet from the free vortex sheet at one leading edge then it can either

(*i*) cross the wing centre line and leave the bound vortex sheet along the other leading edge. To maintain the sense of rotation along its length the line must make a net obtuse-angled turn, while crossing the wing and from symmetry it must cut the centre line at right angles,

or (*ii*) remain on one side of the wing centre line and leave the bound vortex sheet at the trailing edge. If this happens then free vortex sheets must spring from the trailing edge on either side of the centre line. For the line to be able to cross the trailing edge it must make an obtuse-angled turn after crossing the leading edge. The rotation in the trailing vortex sheets is therefore opposite to that in the leading edge vortex sheets.

A third possibility is that the vortex line may enter the bound vortex sheet along one leading edge and then turn downstream or upstream to leave by the same leading edge. Clearly this would involve a change of sign of the shed vorticity somewhere along the leading edge and this arrangement can be ruled out in practice. But vortex lines entering the bound vortex sheet across the trailing edge may also leave by the trailing edge provided that they cross the centre line before doing so. The horse-shoe vortex lines on conventional wings are of this type.

These possibilities are open to any one vortex line. The bound vortex sheet in fact contains lines of each type but the proportion of each depends upon the incidence.

At the leading edges the vortex lines are inclined to the centre line and the rotation is inwards. But just outboard of the attachment lines the upper surface flow has a strong spanwise component, stronger than that on the lower surface. The rotation in this region must therefore be outwards—opposite to that in the leading edge vortex. (Physically, the spanwise induced flow above the wing creates a boundary layer on the upper surface in which the vorticity is of opposite sign to that in the main vortex). Thus a vortex line must make an obtuse-angled turn between the leading edge and the attachment line. It follows that if the portion of the wing between the attachment line develops positive lift then a vortex line which crosses an attachment line must make another turn of 90° or more on doing so.

The vortex lines in the region between the attachment lines may therefore be perpendicular to the free stream or they may try to bend streamwise into the conventional horse-shoe pattern of a wing of finite span. If all adopt the horse-shoe form none cross the attachment lines but bend round to cross the trailing edge in the local mean flow direction (so that there is no load at the trailing edge). In this case a trailing vortex sheet must be shed between the attachment lines which has the same sense of rotation as the leading edge vortex sheets. The vortex lines outboard of the attachment lines remain outboard and where they cross the trailing edge a vortex sheet is formed equal in strength but opposite in rotation to the leading edge vortex sheet.

This flow pattern does not occur in practice. Therefore some of the vortex lines entering the bound vortex sheet along one leading edge must cross both attachment lines and leave the sheet along the other leading edge. The vortex lines crossing the after part of the leading edge remain outboard of the attachment lines and cross the trailing edge to form trailing vortex sheets weaker than those from the leading edge and of opposite rotation. Between the attachment lines two arrangements are possible. Either all the vortex lines are perpendicular to the stream and cross the attachment lines—in which case no vortex sheet is shed from the inner parts of the trailing edge—or some, but not all, may bend round into horse-shoe shape to cross the trailing edge. There is then a trailing vortex sheet between the attachment lines having the same rotations as the leading edge vortex sheets.

At very low incidences the leading edge vortices are weak, and the flow is predominantly of the "attached" type. Some horse-shoe vortex lines may therefore be expected between the attachment lines over the after part of the wing. The remainder will have the same horse-shoe shape close to the centre line but will turn abruptly through a large obtuse angle to cross the attachment lines. Thus the vortex lines which run from one leading edge sheet to the other make five obtuse-angled turns in the bound vortex sheet. This distribution is shown diagrammatically in Fig. 2(*a*). A section through the wake downstream of the trailing edge should show three pairs of trailing vortices (the sheets roll up into vortex cores). One pair from the leading edges rotating inwards, a second much weaker pair from the inner trailing edge rotating inwards and a third pair of intermediate strength leaving the trailing edge farther outboard and rotating outwards.

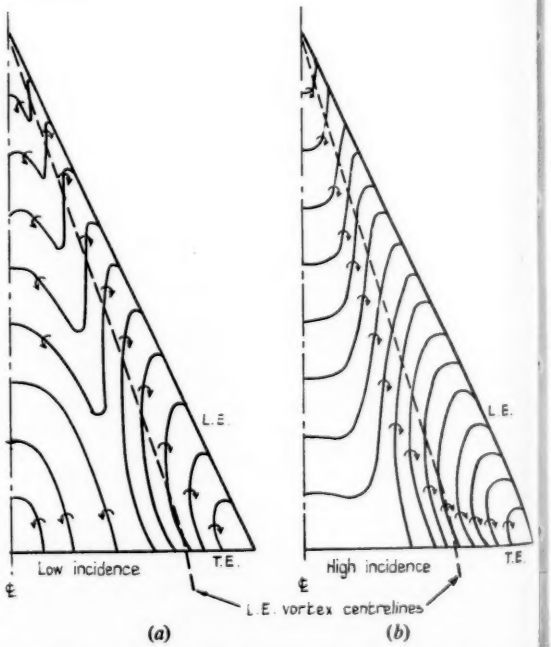


FIGURE 2. Vortex patterns in the surface of a delta wing

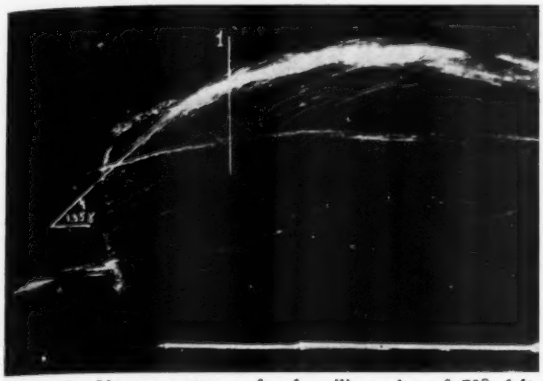


FIGURE 3. Vortex patterns aft of trailing edge of 70° delta wing at 15° incidence.

This vorticity pattern is, except near the trailing edge where no measurements were made, in good agreement with the surface pressure distribution measured at low incidence by Fink and Taylor.[3] The actual extent of the horse-shoe pattern and the strength of the reversed trailing vortices have to be obtained by calculation. Mangler and Smith[4] have found that the leading edge vortex sheet contains about 60 per cent of the total vorticity shed and the strength of the reversed vorticity is about one-half this. The remainder goes into the horse-shoe vortices. If the leading edge vortex strength increases linearly with distance from the apex the vortex lines which remain outboard of the attachment lines must cross the leading edge from about mid-chord aft.

At high incidences the leading edge vortices are much stronger and move inboard so that the attachment lines are almost coincident. The flow pattern is dominated by the separations and there is no reason to suppose that significant amounts of trailing vorticity are generated between the attachment lines (about one per cent of the total according to Mangler and Smith). The vortex lines therefore run spanwise for a short distance on either side of the centre line and then turn forward through 90° as they cross the attachment lines. They turn through an obtuse angle before crossing the leading edges. The triangular regions near the wing tips outboard of the attachment lines must be covered by vortex lines crossing the leading edges and the trailing edge. This vorticity distribution is shown in Fig 2(*b*). Mangler and Smith calculate that the resulting reversed trailing vorticity has about 15 per cent of the strength of the leading edge vortex.

In a water tunnel the reversed trailing vortex can be seen if air is released on the surface almost at the trailing edge. (If it is released out in the flow most of the air is trapped by the stronger leading edge vortex.) Fig. 3 shows a half-model delta wing with air injection close to the trailing edge. The leading edge vortex core is clearly visible as a narrow thread, crossing the trailing edge at about two-thirds semi-span, which ultimately becomes parallel to the free stream. The trailing edge vorticity rolls up into a core which is at first inclined upwards and outwards by the induced velocity field and then turns back to form a spiral around the leading edge vortex. Because they are so weak the horse-shoe vortices shed between the attachment lines cannot be demonstrated in a water tunnel although more detailed measurements[5] in a wind tunnel have shown vorticity of the correct sign at about half semi-span.

4. LIFT PRODUCTION: OTHER PLAN FORMS

As soon as leading edge separation occurs from a delta wing the mechanism of lift production becomes rather involved. We may, however, get an idea of the important factors from the schematic vortex pattern of Fig. 4. There are two distinct vortex systems associated with the flow pattern. As in the case of attached flow the vortex elements A_1B_1, B_2C_2 and C_1D_1 will produce lift under the action of the mainstream. The vortex elements A_2B_3 and C_3D_2 also produce lift under the same action, and lift must be produced by the vortex elements along the lines OB, OC due to the transverse velocity induced by the spiral vortices. The latter source of lift has no equivalent in attached flow and is consequently the main cause of the non-linear lift increment.

As it stands this description does not give any idea of the magnitude of the lift force, but it can explain the variation of lift slope with incidence. The lift slope must be expected to increase rapidly at low incidence when the sections OA_3B_4 and OC_4D_3—and therefore the amount of vorticity along OB, OC—expand rapidly with incidence. But at high incidence the attachment lines coalesce and the pattern remains more or less the same; consequently the lift slope must be expected also to remain more or less constant. Finally, at high incidence a fall-off in lift slope must be expected because the whole pattern breaks down.[6]

Although it has been deduced from considerations of the flow on delta wings the description given does not apply solely to them. By cutting a symmetrical triangle out of the rear centre section of a delta wing a plan form is obtained which must produce a vortex pattern similar to that already described. The essential difference between the two vortex patterns is in the ratios of strengths of the leading edge and the trailing edge vortices. From the sketch of Fig. 5 it appears that the trailing edge vortex sheet must have a total strength which exceeds one half of the leading edge vortex strength. The excess will be roughly proportional to the proportion of the centre line which is removed. The structure of the trailing edge spiral vortex must be expected to vary substantially with the ratio of unswept trailing edge to swept trailing edge. Wing (*a*) of Fig. 5 corresponds to a low and wing (*b*) to a high value of this ratio. In the wake of each half of the wing there will be a vortex sheet which, at each edge, rolls up into spirals of different strengths. In the case of wing (*a*) the strength ratio is about 1 to 1. With a larger proportion of unswept trailing edge the ratio approaches 1 to

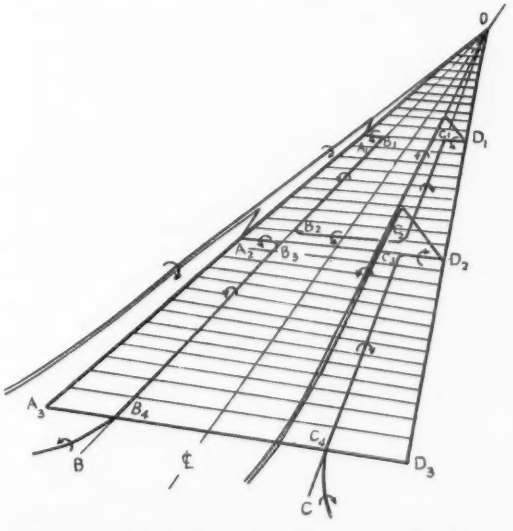


FIGURE 4. Schematic vortex pattern on a delta wing.

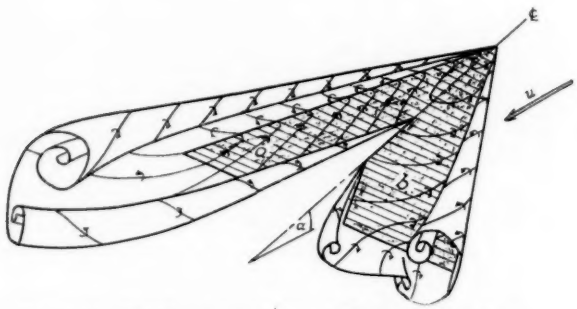


FIGURE 5. The flow around two similar wing plan forms.

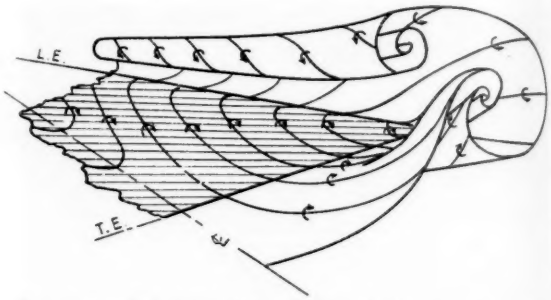


FIGURE 6. Structure of free vortex sheets near the trailing edge of delta wing.

2 and simultaneously one must expect the sheet between the two spirals to develop in the way illustrated in Fig. 6.

The description of the vortex pattern also applies to wings with rounded leading edges provided the spiral leading edge vortex still forms, only in this case the surface vortex lines, after being bent downstream near the leading edge, follow the leading edge for some distance before entering the leading edge sheet. This is associated with the leading edge suction. The amount of attached leading edge vorticity will increase with incidence from zero up to a critical point where the leading edge separation occurs. At the critical incidence it may change discontinuously but then remain more or less constant while the incidence increases further.

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The Distribution of Shear Stresses in an I Section Beam

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WHEN A BEAM is subjected to a static transverse load acting through its flexural centre, the resulting deflection may be considered as the combined effect of the deflection due to bending stresses and the deflection due to shear stresses. In a majority of cases, where the span of the beam is large, or where the shear stiffness is large compared with the bending stiffness, the bending component only need be considered. However, for a short beam, the shear deflection can account for a substantial part of the total deflection. This is especially so in the case of a deep I section beam with a thin web, where the bending stiffness is large compared with the shear stiffness. Moreover, in the case of dynamic loads, Christopherson[1] has shown that for the normal range of elastic impacts between a hard striker and a beam, the shear deflection of the beam is of primary importance, and an assessment of this deflection is necessary to determine impact loads.

The usual method for determining shear deflection is to compute the shear strain energy of the beam and use Castigliano's theorem. Evaluation of the shear strain energy involves specifying the distribution of shear stresses in the section of the beam, and depending upon what assumptions are made, widely varying values may be obtained.

Two commonly used sets of assumptions are taken here, applied to I section beams and the shear deflections obtained from these assumptions are compared with those predicted by a rigorous analysis of the problem.

The assumptions to be investigated are:—

(*a*) Only vertical shear stresses in the web and flanges contribute to the shear strain energy. (Horizontal shear stresses are neglected.) This assumption is widely used and appears, for instance, in Morley[2].

(*b*) The web depth is taken to be the full depth of the beam and assumed to carry only vertical shear stresses. The flanges are taken as the full width of the beam and assumed to carry only horizontal shear stresses, Southwell[3].

The ratio of the shear deflections obtained from these assumptions applied to the slender section (Fig. 1) is

$$\frac{\delta_b}{\delta_a} = 1{\cdot}44.$$

If, as a further approximation in (*b*), thicknesses of web and flanges are assumed small compared with the beam depth and breadth as in Southwell[3], the ratio then takes the value 1·77.

Two beam sections are examined here, the thin section Fig. 1 and the I beam treated by Griffith and Taylor[4] in their work on the soap-film analogy, shown in Fig. 2. It is inevitable that any assumptions made to simplify the procedure for obtaining the shear deflection will favour

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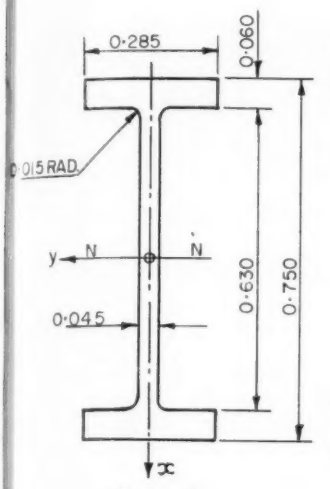

FIGURE 1.

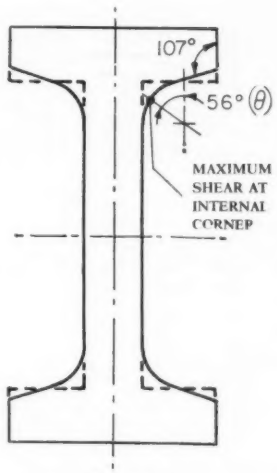

FIGURE 2.

some sectional shapes at the expense of others, but results for the two sections chosen, one relatively squat the other slender, should provide a reasonably clear indication of which assumptions are tenable and which not, for other types of section.

NOTATION

C	modulus of rigidity
D	constant of integration
P	shear force
q	maximum shear stress
x, y, z	co-ordinates
δw_s	shear deflection
θ	angular position of maximum shear stress at fillet (*see* Fig. 2)
ν	Poisson's ratio
τ_{xz}, τ_{yz}	component shear stresses
ϕ	plane harmonic function

ANALYSIS

The basic theory relating to the flexure problem of a beam is given in a convenient form by Timoshenko[5]. Using his notation and approach and noting that the shear strain energy of an element of beam under a shear force P is given by

$$\frac{P}{2}\delta w_s = \frac{\delta z}{2C}\int\int q^2 dx\,.\,dy. \quad . \quad . \quad . \quad (1)$$

Where δw_s is the shear deflection, C the modulus of rigidity and

$$q = \sqrt{[\tau_{xz}^2 + \tau_{yz}^2]}.$$

we find

$$\frac{P}{2}\delta w_s = \frac{\delta z}{2C}\left[\int\int\left(\frac{\partial\phi}{\partial y}\right)^2 dxdy - \frac{P}{I}\int\int\frac{\partial\phi}{\partial y}\left(x^2 - \frac{\nu}{1+\nu}y^2\right)dxdy + \right.$$
$$\left. + \int\int\frac{P^2}{4I^2}\left\{x^4 - \frac{2\nu}{1+\nu}x^2y^2 + \left(\frac{\nu}{1+\nu}\right)^2 y^4\right\}dxdy + \int\int\left(\frac{\partial\phi}{\partial x}\right)^2 dxdy\right]$$
$$. \quad . \quad . \quad . \quad . \quad . \quad . \quad (2)$$

ϕ is a plane harmonic function defined in terms of the component shear stresses as

$$\tau_{xz} = \frac{\partial\phi}{\partial y} - \frac{P}{2I}\left[x^2 - \frac{\nu}{1+\nu}y^2\right], \qquad \tau_{yz} = -\frac{\partial\phi}{\partial x}$$

and has values in the boundary defined by

$$\phi_b = \frac{P}{I}\left[\int_{y_0}^{y}\frac{x^2}{2}dy - \frac{\nu}{2(1+\nu)}\frac{y^3}{3} + D\right],$$

D being a constant of integration and ν, Poisson's ratio. The shear deflection follows upon evaluation of the right hand side of equation (2) which involves finding ϕ for all points on the section considered. The relaxation technique was used for this in the case of the slender I beam and the mesh giving the final values of ϕ over the section is shown in Fig. 3.

Griffith and Taylor conveniently provide a diagram giving contours of shear stress in their beam in terms of the applied load. It was therefore quite a straightforward matter to transfer these contours on to a grid and perform the integration required by equation (1).

RESULT FOR SHEAR DEFLECTION

With the " scale " of the ϕ diagram chosen as indicated in Fig. 3 and with $\nu = 0{\cdot}3$ and $C = 11{\cdot}5\times10^6$ lb./in.^{2}, the following values are obtained

$$\frac{P}{I} = 2{\cdot}4506\times10^5 \text{ lb. in.}^{-4}, \quad D = 0{\cdot}0040811$$

and the shear deflection per unit length $(\delta w_s)/(\delta z)$ given in column c of Table I. The assumptions given by Morley and Southwell, applied to the same section, yield the values in columns a and b respectively. Values for the Griffith and Taylor beam are similarly arranged, those obtained by an approximate method being calculated for a beam having an equal second moment of area to the actual beam, but with square corners and parallel flanges (shown dotted in Fig. 2).

A check on the accuracy of the solutions, that the integral of the shear stress τ_{xz} over the whole section should equal the applied shear force P, showed an accuracy of 0·5 per cent for the calculation.

The use of Southwell's assumptions, which are for thin sections, in the case of the Griffith beam is obviously inappropriate and is included here only for completeness. The result for the slender section, from these assumptions, where one would have expected a reasonably close correlation, is only a poor approximation to the true value. Morley's assumptions are much more satisfactory and the use of these is obviously justified.

One other set of assumptions, combining both methods, is suggested for comparison. If we assume that the flanges of a beam carry both horizontal and vertical shear stresses, and the web carries only vertical shear, we obtain the values given in column d of Table I. The value d is more accurate than a for the slender section and less so for the squat section, the order of accuracy being approximately equal (applied to opposite sections).

TABLE I

	a *Morley*	*b* *Southwell*	*c* *This analysis*	*d* *Suggested approximate method*
Slender I Section, Fig. 1	3·29	4·74	3·45	3·41
Griffith and Taylor beam, Fig. 2	3·98	9·36	4·00	4·19

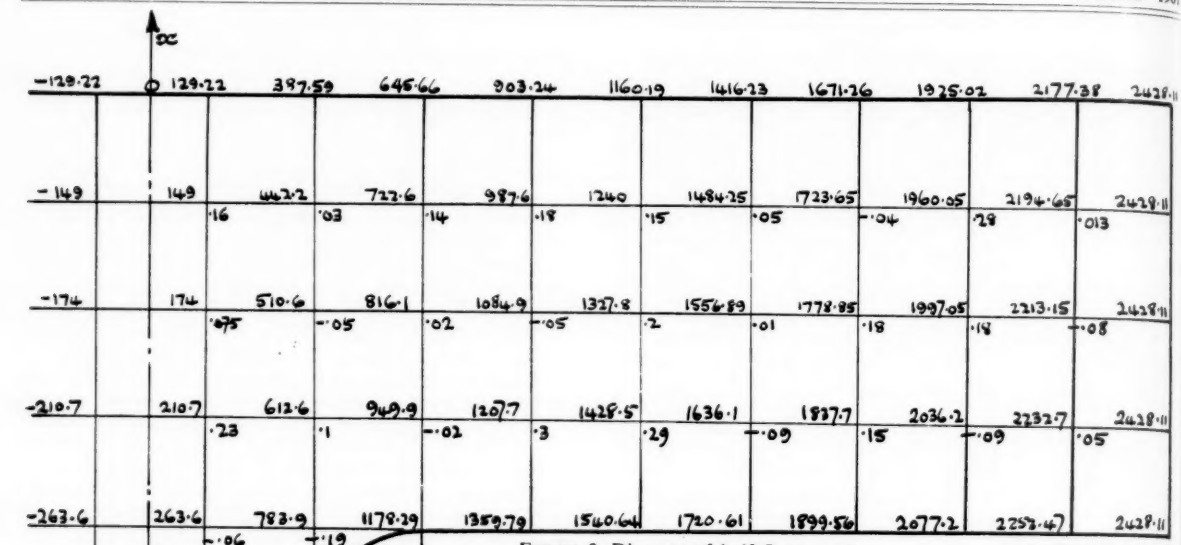

FIGURE 3. Diagram of half flange and part of web giving values of ϕ for section having fillet radius = 0·015 in. Mesh size = 0·015 in.

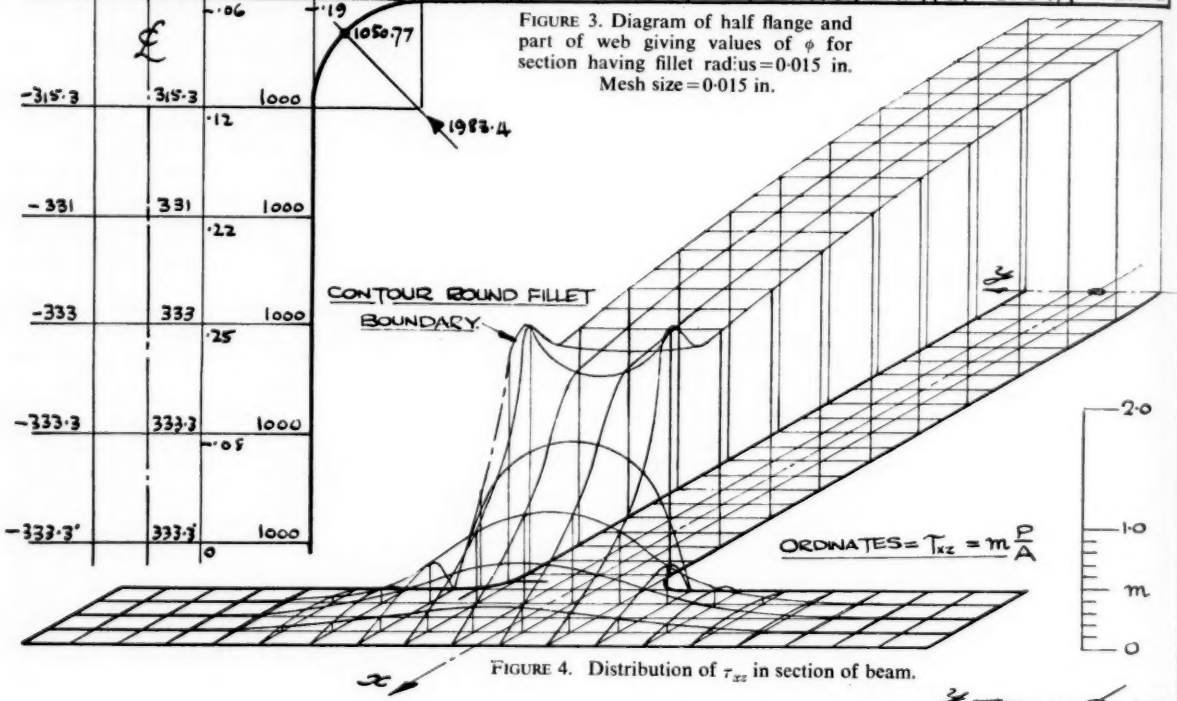

FIGURE 4. Distribution of τ_{xz} in section of beam.

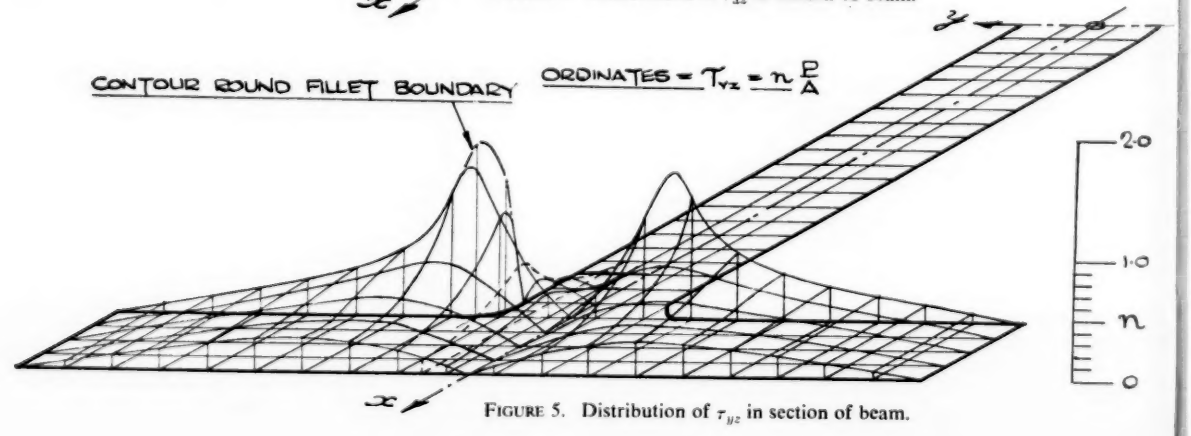

FIGURE 5. Distribution of τ_{yz} in section of beam.

Figures 4 and 5 show the distribution of shear stresses in the cross section of the slender beam. In Fig. 5 raised grid lines have been omitted for the sake of clarity in the region $x < 0{\cdot}315$, y negative, and for the same reason only one fillet contour has been shown in each diagram. The distributions found agree well with the contour lines given by Griffith and Taylor for their I beam.

STRESS CONCENTRATION AT RE-ENTRANT CORNER

The initiation of shear failure depends upon the maximum shear stress occurring in the cross section under a given shear force, and accordingly we examine the concentration of shear at the fillet of the slender section and compare the values obtained with those found by Griffith and Taylor.

Two cases are considered, the first having the 0·015 in. radius already used, and the second a 0·030 in. radius. A relaxation net size equal to that shown in Fig. 3 was used for the larger radius, and a mesh half this size for the smaller radius, to maintain a consistent order of accuracy. Having obtained the ϕ diagrams for the two cases the component stresses τ_{xz} and τ_{yz} and the maximum shear stress q were calculated for each point on the fillet boundary, interpolation then giving the value and position of the maximum shear stress in the corner.

If θ is considered as shown in Fig. 2 swept in both cases from the centre point of the radius, then the maxima occur at $\theta = 67°$ and $\theta = 89°$ for the 0·015 and 0·030 in. radii respectively. Expressed as a percentage of the value of the maximum shear at the neutral axis, these maxima are 95·8 per cent and 82·6 per cent respectively.

For the I section beam used by Griffith and Taylor, which had a fillet radius to web thickness ratio of 0·73, the shear stress concentration at the fillet was found to be 80 per cent of the maximum value at the neutral axis. This compares favourably with that obtained for the slender I section with a 0·030 in. radius, where the fillet radius to web thickness ratio is 0·67. Comparisons on the grounds of this ratio must, however, be limited to geometrically similar sections as there appears to be no correlation between the results for the I beams given above and the result for the T beam which Griffith and Taylor also analysed.

The stress concentration in the fillet of the slender section, is located to a greater extent in the web rather than the flange. This is noticeable also in the results of Griffith and Taylor for both I and T section beams, where for the former $\theta = 56°$ approximately. This smaller value of θ is almost certainly due to the comparatively large chamfer angle between the underside of the flange and the web of their beam, about 107°, whereas for the slender section the surfaces are parallel. The usual value of this angle in a commercially rolled steel section is 98°.

An angle greater than 90° appears to be desirable then on three counts: one, it facilitates the rolling process; two, the underside of the flange gives a lesser contribution to bending stiffness than the upper and three, for a given fillet radius it has a smoothing effect on the shear stress contours in the region of the fillet, displacing the stress concentration upwards towards the less highly stressed region.

In the case of the slender I section, doubling the fillet radius does not give a very large reduction in shear stress and moreover, results in moving the position of the maximum farther into the web, where a higher state of stress will in general exist. A more beneficial effect could be obtained by making the fillet elliptical in form (major axis parallel to the web) since this would tend to move the concentration of shear round to the underside of the flange and smooth the shear contour in this region.

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Stress Concentrations Around Cut-outs in a Cylinder

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A CONSIDERABLE AMOUNT of theoretical investigation has been undertaken recently, into the stress concentrations arising in the vicinity of cut-outs in aircraft pressure cabins. Papers which analyse the stress concentrations around circular, elliptical, and square reinforced cut-outs, under various loading conditions have been presented by Mansfield[1], Hicks[2] and Wittrick[3].

In all of these investigations, the problem of the cut-out in a cylinder has been reduced to a problem of an infinite plane sheet containing a hole, and the effects of the curvature have been generally assumed to be insignificant.

One of the few attempts which allows for the curvature effect in a cylinder subjected to direct loadings is given by Lurie[4] and the purpose of this note is to compare the curvature effect predicted by Lurie, with experimental results conducted on unreinforced cut-outs using a frozen stress technique[5].

The models which were used in the frozen stress investigation were cast using Araldite B, and were machined to the dimensions given in Fig. 1. The experimental loading apparatus which was developed for these investigations enabled the cylinder to be subjected to direct axial tension or compression, torsion, and internal pressure loading. Diametrically opposed cut-outs were arranged in order to eliminate any bending effects, and the internal pressurisation experiments were arranged so that the radial pressure loading across the hole was not reacted by its boundary but by an external structure. This condition is consistent with the assumptions made in the analysis.

The arrangement of the polariscope is shown in Fig. 2. A crossed diffused light polariscope was used with mono-

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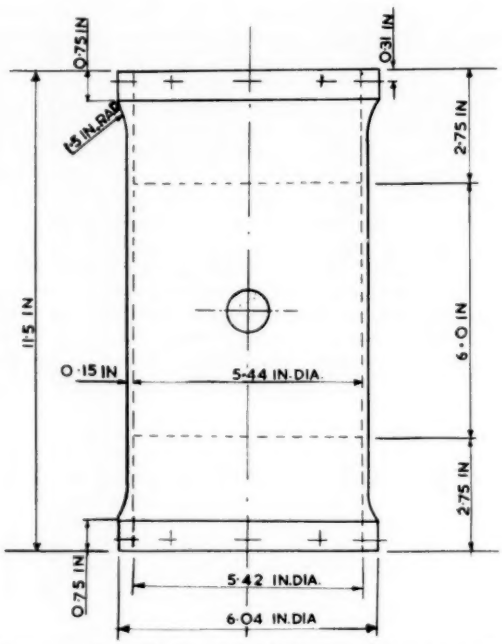

FIGURE 1. Dimensions of the Araldite models used in the experiment.

chromatic sodium light. The polariser was placed inside the cylinder with the cut-out under examination between it and the analyser. By making use of this arrangement, the stresses in the far wall of the cylinder did not interfere with those being measured.

NOTATION

a, b	semi-axes of elliptical hole in direction of x and y
A	cross-sectional area of reinforcement
f_1, f_2	tensile stresses at infinity in x, y directions
R	shell radius
$\widehat{ss}$	tangential stress
t	shell thickness
u, v	displacements in the surface medium
x, y	Cartesian co-ordinates
θ	polar angle in circle plane (*see* Ref. 3)
λ	curvature correction term
ν	Poisson's ratio
$\phi(x, y)$	displacement function.

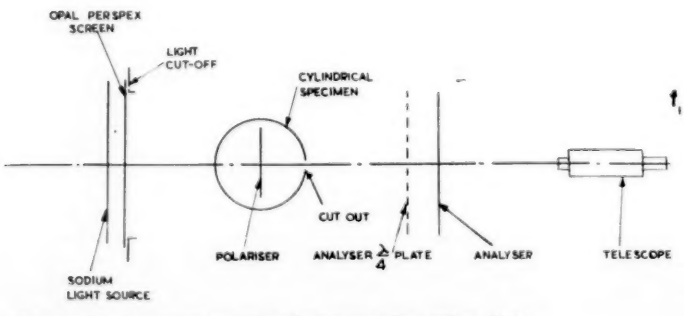

FIGURE 2. Arrangement of optical bench for diffuse light polariscope.

The general equations for a reinforced elliptical hole have been developed by Wittrick who makes use of the complex stress function and the method of conformal transformation which was developed by Muskelishvili[6] and used extensively by Savin[7]. The tangential stress around a reinforced elliptical hole in a sheet under tension at infinity (Fig. 3) can be expressed as

$$\widehat{ss} = \left[\frac{2}{P} - (1-m^2)\frac{Q}{P^2}\right]\left[\frac{1}{2}(1-m^2)(f_1+f_2) - \frac{(f_1-f_2)}{Q+1}(\cos 2\theta - m)\right],$$

$m = \dfrac{a-b}{a+b}$, where a and b are the semi-axes of the ellipse in the direction of x and y.

$$\bar{R} = \tfrac{1}{2}(a+b),$$

$$P = 1 + m^2 - 2m\cos 2\theta,$$

$$Q = \frac{2P}{(\bar{R}t/A)P^{3/2} + (1-m^2)(1+\nu)},$$

A = cross-sectional area of reinforcement (in general variable).

It should be noted that this equation is valid only if Q is constant.

For an unreinforced elliptical hole, the parameter Q which defines the geometry of the reinforcement becomes zero and the tangential stress becomes

$$\widehat{ss} = \frac{2}{P}\left[\frac{1}{2}(1-m^2)(f_1+f_2) - (f_1-f_2)(\cos 2\theta - m)\right], \quad (1)$$

and for a circular hole

$$\widehat{ss} = f_1 + f_2 - 2(f_1 - f_2)\cos 2\theta. \quad (2)$$

Equations (1) and (2) are compared with the experimental results in Figs. 4 and 5.

Lurie[4] in his analysis of circular holes in curved shells neglects the displacements u and v in the surface medium when calculating the change in curvature of the shell, and this is expressed only by the radial component of the displacement.

The problem then reduces to the determination of a

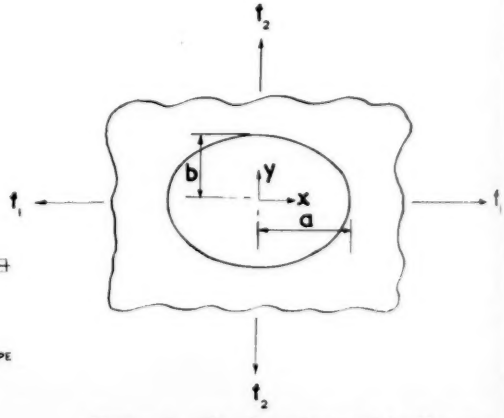

FIGURE 3. The dimensions and loading of a cut-out.

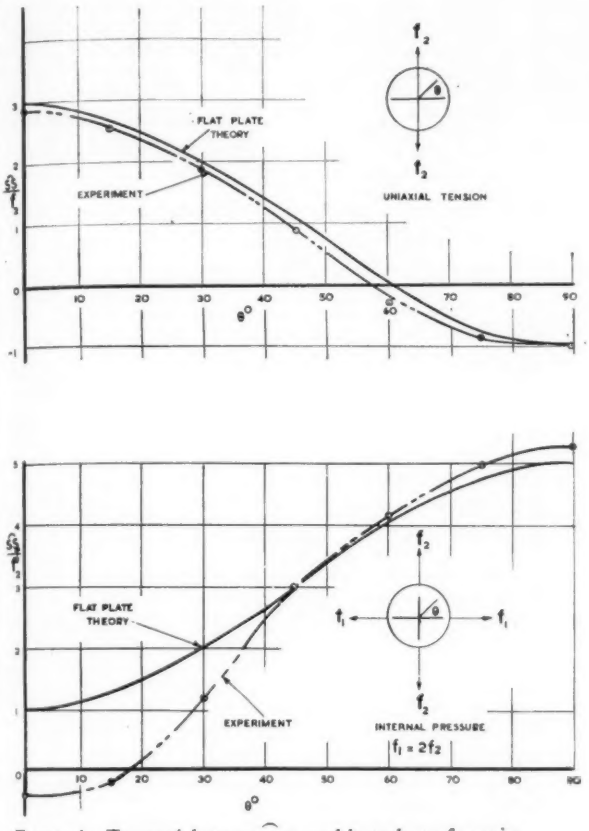

FIGURE 4. Tangential stress $\widehat{ss}$ around boundary of unreinforced circular hole in cylinder.

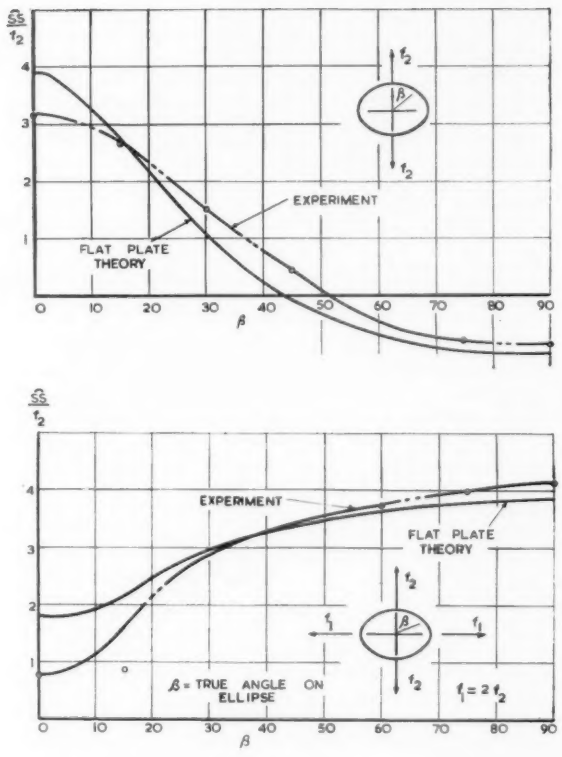

FIGURE 5. Tangential stress $\widehat{ss}$ around boundary of unreinforced $\sqrt{2}:1$ elliptical cut-out in cylinder.

displacement function $\phi(x, y)$, which satisfies the differential equation

$$\Delta\Delta\Delta\Delta\phi + \frac{12(1-\nu^2)}{(Rt)^2}\frac{\partial^4\phi}{\partial x^4} = 0,$$

where R and t denote the shell radius and thickness and

$$\Delta = \frac{\partial^2}{\partial x^2} + \frac{\partial^2}{\partial y^2}.$$

If $a^2/Rt \ll 1$, where a is the radius of the hole, then the tangential stress is given by

$$\widehat{ss} = (f_1+f_2) - 2(f_1-f_2)\cos 2\theta + \sqrt{[3(1-\nu^2)]}\frac{\pi a^2}{4Rt} \times \times [2f_1 + (f_2-3f_1)\cos 2\theta]. \quad (3)$$

It is seen that equation (3) consists of the flat plate solution of equation (2) plus a curvature correction term.

For the case of the uniaxial tension ($f_1=0$) the maximum stress given by equation (3) becomes

$$\widehat{ss} = f_2\left[1 + 2\cos 2\theta + \sqrt{[3(1-\nu^2)]}\frac{\pi a^2}{4Rt}\cos 2\theta\right].$$

When $\theta=0°$, and if $\nu=0{\cdot}3$, $\quad \widehat{ss} = 3f_2\left[1 + \dfrac{0{\cdot}43a^2}{Rt}\right]$.

When $\theta=\pi/2$, $\quad \widehat{ss} = -f_2\left[1 + \dfrac{1{\cdot}29a^2}{Rt}\right]$.

For the case of internal pressure $f_1=2f_2$, and

$$\widehat{ss} = f_2\left\{3 - 2\cos 2\theta + \sqrt{[3(1-\nu^2)]}\frac{\pi a^2}{4Rt}(4 - 5\cos 2\theta)\right\}.$$

When $\theta=0°$, then $\quad \widehat{ss} = f_2\left[1 - \dfrac{1{\cdot}29a^2}{Rt}\right]$,

and when $\theta=\pi/2$, $\quad \widehat{ss} = 5f_2\left[1 + \dfrac{2{\cdot}32a^2}{Rt}\right]$.

For the experiments carried out $a^2/Rt = 0{\cdot}88$.

Hence the curvature correction term λ becomes:—

Uniaxial case. $\theta=0°$, $\lambda=1{\cdot}38$,
$\theta=\pi/2$, $\lambda=2{\cdot}13$.

Biaxial case. $\theta=0°$, $\lambda=-0{\cdot}13$,
$\theta=\pi/2$, $\lambda=3{\cdot}04$.

The limiting geometry condition which is specified by Lurie, is not strictly fulfilled in this section of cut-out experiments. However, the close agreement between the flat plate theory and these experiments tends to suggest that up to values of $a^2/Rt = 0{\cdot}88$, the flat plate theory is adequate. Only for the case of a biaxial tension at $\theta=0°$, is a better agreement with the experimental results obtained by using a curvature correction effect.

Research work is continuing on this subject, and it is

hoped to investigate the correlation between flat plate theory and additional experiments having large values of the parameter a^2/Rt.

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Correspondence

METAL CONSTRUCTION

ON PAGE 70 of the January 1961 JOURNAL there is an account of a book* by Robin Higham, published by G. T. Foulis & Co. Ltd., and a reference to the "Calcutta" flying boat which your reviewer, properly, has corrected.

I have had some correspondence with Mr. Robin Higham. His first letter clearly shows that he has read the Official Report "Parliamentary Debates in the House of Lords, April 13th 1943." On pp. 151 and 152 Lord Treviot opened the Debate on Short Brothers. I cannot record here all the Debate, but Lord Treviot expressed his surprise that Short Brothers should have been Nationalised under Defense Regulation 78, which is the "Defense of the Realm Act." It makes me wonder how Short Brothers could ever be considered a danger to the British Empire. It is very much the reverse, as on page 165 Lord Kenilworth said, to quote part only of his speech, "and we know the wonderful testimonies that have been paid to the young men of the R.A.F. in the Battle of Britain. I would remind your Lordships that the tools with which that Battle was won were made by this particular industry."

Actually he was referring to me, because he never met my late brothers, Horace and Eustace Short. I was temperamental, and fortunately, a visionary. Horace Short did not live to see a stressed skin metal aircraft made of "Duralumin."

In 1920 I exhibited the "Silver Streak" at Olympia. This was the first stressed skin metal aircraft in the world capable of bearing an internal hydraulic pressure of seven pounds per square inch. This test which I made on a section of the "Silver Streak" fuselage was witnessed by our test pilot, Mr. John Lankester Parker in September 1919, before I completed the "Silver Streak." But the use of "Duralumin" for aeroplane and flying boat construction had been forbidden by the Director of Technical Development, Air Ministry. In doing what I did without permission I had offended him. The "Silver Streak" was purchased by the Air Ministry, and flown to South Farnborough by Mr. John Lankester Parker. But R.A.F. pilots were forbidden to fly it. The R.A.F. pilots then signed a "Round Robin" begging to be allowed to fly it. They were then allowed to, but told to fly it *without load* and make no steep banks in it. If I know anything about R.A.F. pilots they did what they liked with it. It was then taken into a shed for a destruction test. The planes broke at the estimated safety factor, but they failed to break the fuselage. But I received no more orders. I then built an all-metal hull for the F.5 type flying boat, with wooden-built planes. The wooden-built F.5s were designed by either the Admiralty designers, or the Technical Department. They wanted me to alter the construction of the all-metal hull. I refused to do so, saying "That is not stressed skin metal construction." I was then asked to sign a letter, taking full financial responsibility. This I gladly signed. The hull was successful and I was paid the £10,000 I had risked but I received no further orders. Instead an order was given to the Supermarine Aviation Co. Ltd. for six stressed skin all-metal hulls for the "Southampton" type flying boat. Again without an order I started to build Singapore I but the late Sir Geoffrey Salmond, a member of the Air Council, came to Rochester and gave me an order for it. Without engines or instruments it cost £20,000. This was the flying boat in which Sir Alan Cobham flew round Africa.

"Duralumin" was first made by the German metallurgists and it was used too in Zeppelin airships, aeroplanes and flying boats, in which the fuselages were square in section.

It is obvious that a fuselage or hull would distort under an internal pressure of 7 lb. per square inch. Now aeroplanes flying at 40,000 feet are pressurised to 8 lb. per square inch to enable passengers to breath, without oxygen masks, which would be very inconvenient. Again, before building the "Silver Streak" I disproved the theory of "a sporadic kind of intercrystalline corrosion" by an experiment long before I built the "Silver Streak" at Olympia Aero Show in 1920. In "The Air Annual of the British Empire, 1929" on page 458, second paragraph, appears this statement:—"Duralumin is more costly than steel, and is not so strong as steel may be, even relative to its low density. It is troublesome to manipulate, and requires special heat treatment between processes. It is also an unreliable metal, being subject to a sporadic kind of intercrystalline corrosion which may eat the heart out of it, so that a part loses all its strength, and this weakening may proceed without evidence visible on the surface of the metal." But beginning on page 580 of the same journal is an article by the late Major Mayo of Imperial Airways Ltd. It is headed "Short Brothers (Rochester and Bedford) Ltd." It includes five photographs, one of which includes the water tank for testing model hulls, at a cost of £4,000. In 1929 we were only ten years from war with Hitler's Germany, and all the aircraft we used in that war were made of "Duralumin," like the "Silver Streak" of July 1920, whether made by Short Brothers or any other company who, so belatedly, followed my example.

The system of aircraft construction was patented by me. After the usual search the Patent Office gave me a complete patent in 1921.

19*th January* 1961. OSWALD SHORT

**Britain's Imperial Air Routes* 1918 *to* 1939. Robin Higham. G. T. Foulis. London, 1960.

THE BRANCHES

The chronological sequence in the formation of the Branches is broken this month, as February 1961 is the 10th anniversary of the CHESTER Branch, and this exception of sequence is by way of congratulation.

THE idea that a Chester Branch be formed first arose during a discussion late in 1948 between Dr. C. G. Williams (now Director and General Manager, "Shell" Research Limited) and Mr. E. L. Bass (Head of the Technical Group of the Aviation Division of Shell International Petroleum Company until he retired recently); both are Fellows of the Society. Dr. Williams found plenty of support for the idea in the Chester area and he promoted an inaugural Meeting under the Chairmanship of Mr. N. A. White. In November 1950, this Meeting elected a temporary organising Committee under the Chairmanship of Mr. J. G. Dawson; this Committee formed and nurtured the embryo Branch until it was formally opened by the President of the Society, Major G. P. Bulman, on *7th February* 1951.

Under the guidance of its first President, Mr. J. C. Corby (then General Manager of the de Havilland Aircraft Co., Broughton, and now General Manager of the Engine Division, Manor Road Works, Hatfield) and the Chairman Mr. Dawson, the Branch flourished and expanded. Most of the members worked for the de Havilland Aircraft Co., Broughton, Chester; Electro-Hydraulics Limited, Warrington, and The Thornton Research Centre; but substantial numbers came also from the Royal Naval Air Station, Stretton, the Royal Air Force Station, Hawarden, and private individuals. At the end of the first session, membership had risen to 143; and is now about 235.

Professor A. D. Baxter (then Head of the Aircraft Propulsion Department of the Cranfield College of Aeronautics, and now Director of the de Havilland Engine Co. with particular interest in nuclear and rocket propulsion) gave the first lecture to the Branch. This lecture entitled, "Power Plants for High-speed Flight" and later published in the JOURNAL, set a high standard which Chester has tried, successfully on the whole, to maintain ever since. Rather unusually, however, the Branch was formally opened not at the first meeting but at the second (7th February) when Mr. D. L. Ellis of the Aircraft Division of the English Electric Company Ltd., gave a talk entitled "The Use of Wind Tunnels in Aeroplane Design." Since then lecture Meetings have been held usually on the second Wednesday of each month from September to April in each session; at first they were held at the Grosvenor Hotel, Chester, but for some years they have been held in the Lecture Theatre at the Grosvenor Museum, Chester.

It is impossible to record all the outstanding events which have occurred during the ten years of existence. The lecture programme has covered almost every conceivable aspect of aeronautics from—for instance, "Bird Flight" by J. Laurence Pritchard, "Gliding" by V. H. Slingsby, and "Man Powered Aircraft" by B. Shenstone via "Aircraft in the Oil Industry" by Douglas Bader to "Interplanetary Flight" by E. Burgess in 1952 and A. V. Cleaver in 1953. Most of the lectures have been given by men who are experienced and often pre-eminent in aeronautics, but, a number have been given by young members of the Branch in the "Lecturette" series. For lecturettes young people are encouraged to research and write on aeronautical subjects, and two or three of the best papers are presented by the authors at a lecture Meeting. Prizes are given for the best papers, and audiences have been pleasantly surprised at the high standard achieved in some of the papers; the Lecturette series has helped to improve the experience, confidence and initiative of junior members.

The first Main Lecture was in 1954, and the second is to be on the 8th March 1961, to mark the 10th Anniversary of the Branch. The lecture, on "Low Speed Problems of High Speed Aircraft," will be by A. Spence and D. Lean of the R.A.E.

The Chester programme has not neglected foreign experience of aeronautics. For instance, Mr. D. W. Finlay, Chief of Preliminary Design for the Boeing Airplane Corporation, flew from U.S.A. especially to give the Opening Lecture of the 1959/60 Session, which was entitled "The Development of the Boeing 707." In the present session there have been lectures on the Douglas DC-8 and the Caravelle, each presented by members of the producing companies.

1958 saw the first Christmas Lecture for young people; and Professor A. D. Baxter twice gave a lecture entitled "Rockets." In 1959 "Bill" Bedford talked about "The Life of a Test Pilot," and recently Mr. J. R. Joyce lectured on "Oil in Aviation" with the aid of demonstrations and films.

Brains Trusts are always interesting and, during the summer there are the usual visits to places of aeronautical and general engineering interest; unlike the visits, the annual dances have not all been financial successes but are always a social success.

One of the more important events organised by the Branch was the Aeronautical Show and Garden Party, in May 1958, which was held on the Airfield used by de Havillands, Broughton. The aim was to provide an event for members and friends of the Society in the North comparable with the Garden Party which the Main Society stages in the London area, and was the first to be organised on such a scale by a Branch of the Society. The opening ceremony was performed by Sir Arnold Hall, then President of the Society. A description of the Show was given in the JOURNAL for August 1958; it is sufficient to recall that the event was held as a real Garden Party, the programme containing an extensive flying display drawn from the R.A.F., industry and private owners of aircraft, with a complementary static display of aircraft and a comprehensive exhibition of equipment and auxiliaries. Twelve hundred attended the Show, which was a great social success and which recruited 35 new members to the Branch.

During the 1956/57 session a Branch Lapel Badge was designed by a Branch member, Mr. B. H. Jones, and this has proved a very popular feature.

As with other Branches, much is owed to the numerous firms and individuals (both outside and inside the Committee) who have spent time, effort and money in providing the Branch with a very fine programme.

The Branches Page has recently completed its own first Anniversary, and congratulates Chester, as does the Branches Committee (to whom this was first referred) on their tenth Anniversary.—G.W.-W.

Hatfield Branch Young People's Lecture

On Wednesday 4th January in the hall of Hatfield School, a Young People's Lecture arranged by the Hatfield Branch was given by Mr. J. E. Allen, B.Sc.(Eng.), A.F.R.Ae.S., A.M.I.Mech.E., A.F.I.A.S., Head of Projects, Weapons Division, A. V. Roe Ltd., on "Space Flight 1961." Introducing the Lecturer, Mr. D. R. Newman, the Chairman of the Branch, stated that as the Branches of the Royal Aeronautical Society's main purpose was to spread the knowledge of Aeronautics, they had arranged for a Young People's Lecture and hoped to make it a yearly event.

Mr. Allen first explained the various orbits made by satellites around the earth and then introduced a number of rockets which have been used to send either probes or satellites—the "Polaris" missile, the "Vanguard" rocket which sent a 3 lb. satellite into the atmosphere, the "Thor" carrying a 200 lb. rocket, "Able" with its satellite the "Discoverer", the "Atlas" with its satellite the "Score", and finally the "Saturn" capable of sending a 200 ton satellite into the atmosphere, which the Americans hope to fire in 1961. As each rocket was introduced, an accurately scaled model appeared on the Speaker's table, until he was literally surrounded with rockets. This helped his audience to appreciate the size of "Polaris" and the dimensions of the "Saturn". The possibility of using satellites for communication was also explained with the assistance of a short film. At the end of the Lecture, Mr. Allen answered questions from a very appreciative audience, which consisted of boys and girls from schools within ten miles of Hatfield.

Awards to Young Brough Branch Members

At the end of the January lecture meeting of the Brough Branch, cash awards were made to young members of the Branch who have prepared papers for the N. E. Rowe Medals competition. £5 was presented to W. Bishop, whose paper was adjudged the best submitted by a Branch member, and £1 each to L. W. Diment and J. M. Reeves.

Graduates' and Students' Section

The Flight Testing of V.T.O.L. Aircraft

On Wednesday 8th February 1961, Mr. T. W. Brooke-Smith, formerly Chief Test Pilot, Short Brothers & Harland Ltd., gave an interesting and informative lecture based on his experiences when flight testing the Short SC.1 V.T.O.L. aircraft.

Mr. Brooke-Smith began by describing how a test pilot sets out to arm himself with as much knowledge as possible relating to the configuration and role of a new prototype aircraft. He did this for three reasons:—to make himself as useful as possible within the design team, to ensure that the best possible approach is made to facilitate the future task of flying and flight testing the aeroplane, and to prepare himself to approach the initial flight stage in as safe, experienced and sensible a fashion as possible.

It was suggested that the fixed-wing pilot becomes innured to the fixed-wing concept of flight—where speed relative to the air is the basic requirement for flight itself and for safety in the air. The stalling speed becomes of prime importance and it was thus Mr. Brooke-Smith's first task in his approach to V.T.O.L. to rid himself of the fixed-wing complex. This was achieved by some hours of helicopter flying in which he became accustomed to the new environment of stationary flight and of flying backwards, sideways and vertically. The basic picture of the problems of stability and control—or "flyability"—was established, and then he went on to acquaint himself with the Rolls-Royce Thrust Measuring Rig, or Flying Bedstead. Here for the first time he was able to practice vertical flight supported solely by jet-thrust and control balance by means of small subsidiary jets of air from "puffer pipes" positioned forward, aft and athwartships. As the SC.1 disposed a delta plan form experience was gained on the Avro 707A—the precursor of the Vulcan bomber.

The salient features of the SC.1 were discussed with the aid of slides and then the three phases of the flight testing programme were described. These were (*i*) conventional flight (*ii*) hovering flight, and (*iii*) transient flight. The conventional phase set out to prove the airframe and power plant as a satisfactory vehicle for the experiment to follow. Initially testing was carried out with only the propulsion engine installed, and then with the vertical lift engines in position, testing proceeded which involved lighting-up and running the lift engines in the air and generally proving them safe throughout their r.p.m. range across the normal band of aircraft air speed in wing-borne flight. As it seemed likely that the flow pattern of the large quantity of high velocity air being passed through the lift engines might adversely affect the aerodynamics of the aircraft, the tests were carried out in such a manner that the engines were sealed by four "lids" which were removed in turn as the flight characteristics were established. The gills forward of the lift engines on the SC.1 were tested to determine the optimum setting commensurate with engine handling taking into account drag and other effects—this proved to be at the 60 per cent open position. Engine lighting-up in flight was then carried out. With increase in lift engine r.p.m., a strong nose-up pitching moment was experienced which was beyond the range of the elevator to control, so the ailerons were drooped 5°. This proved insufficient so it was decided to increase the elevator down travel. This resulted in a reduction of up-elevator for landing—the latter performance becoming a very sporting manoeuvre indeed! A further modification was carried out which was entirely satisfactory.

Mr. Brooke-Smith went on to discuss the enormous value of the flight simulator from which they were able to establish the stiffness of the stabilisers, before the SC.1 had been flown in hovering flight.

Initial phases of the hovering trials were carried out in a gantry which enabled the aircraft to fly quite freely within a predetermined envelope. Outside this envelope cables which were attached to the aircraft restricted it from further movement. Early hovering trials were limited to a wind speed of 8 kts., but it was soon found that wind had little effect and flying went ahead without reference to its speed or direction and on one occasion gusts of over 42 m.p.h. were recorded on the gantry site.

Free vertical take-offs and landings were carried out from a small metal platform on the airfield, and one landing on the grass to observe the effects of the downward jet efflux showed that they were negligible.

The transient phase was tackled in three stages. First, stability and control and lift and propulsion engine behaviour were investigated at altitude every 10 knots from 145 kts. to 75 kts. The second stage involved a vertical take-off to 30 or 50 ft. above the runway at R.A.E. Bedford and a series of runs at increments of 10 kts. from zero to 85 kts.—decelerating at the end of each run. The final phase was to carry out the full sequence in one flight and this proved uneventful.

The lecture concluded with a film depicting some of the SC.1 flight trials including one or two early transitions.

Paris Aero Show

Arrangements continue for a weekend visit to the Paris Aero Show, leaving London on Friday 2nd June and returning on Sunday 4th June. Further negotiations with a charter firm have indicated that the approximate cost *will not exceed* £12 including flight and surface fares and hotel accommodation, and as the party must be limited to approximately 35, early application is advised. A deposit of £3 should be sent with applications to the Hon. International Visits Secretary, P. Hampton, Staff Mess, Royal Aircraft Establishment, Farnborough, Hants. Further details will be published on this page as soon as they become available.

Man Powered Flight

On Wednesday 12th April, at 7.30 p.m., Mr. B. S. Shenstone, M.A.Sc., F.R.Ae.S., F.C.A.I., A.F.I.A.S., Chief Engineer and Director of British European Airways, will lecture to the Section on Man Powered Flight. Mr. Shenstone is generally regarded as an authority on this subject and has actively concerned himself for many years with fostering progress towards achieving man powered flight. The Man Powered Aircraft Group of the Society was formed in February 1959, and interest was stimulated by the offer of a financial prize by Mr. Henry Kremer in November 1959 for the first successful controlled flight under agreed conditions. A number of designs are at present in the process of construction and some of these should be ready for an attempt to win the prize during this year. Mr. Shenstone's lecture promises to throw much light on the progress which has been made towards the goal of man powered flight.

Opportunities at Farnborough

Following the notice on this page in the January JOURNAL regarding the opportunity which exists for members to visit a particular department at Farnborough, interest has been shown in the Aerodynamics Department and the Hypersonic Section. It is therefore proposed to organise a visit in the near future. Any other members who would like to visit these or other departments should contact the Hon. Visits Secretary as soon as possible.

Future Visits

The following visits have been arranged:

Wednesday 19th April, National Gas Turbine Establishment at Pyestock. (Afternoon).

Wednesday 10th May, Handley Page Ltd. (Afternoon).

Application for the visits should be made to the Hon. Visits Secretary, N. R. Craddock, 5 Oxleay Road, Harrow, Middlesex (Tel: Pinner 3633), *at least three weeks before the date of the visit.*

"O.K., now what?"

THE LIBRARY

Reviews

AN ELEMENTARY TREATISE ON THE MECHANICS OF FLUIDS. *W. J. Duncan, A. S. Thom and A. D Young. Arnold, London. 1960. 714 pp. Diagrams. 70s.*

Many books have been written on fluid mechanics for university students of engineering. This one is quite different from the others; it gives to the subject a firm foundation of sound principles, hitherto found only in more advanced treatises. At the same time it avoids difficult mathematics that would be beyond the capabilities of an ordinary engineering student. Any mathematical techniques which might be unfamiliar to the student have been fully explained, and even on comparatively simple points reminders are often put in to help the reader. Very little use is made of vector analysis and tensors are only briefly mentioned.

In view of the length of the book one wonders at first whether the word "elementary" is appropriate, but further study shows that the authors have taken great trouble to achieve the aim stated in the preface "of providing a systematic and easily understood account of the basic principles of the science of the mechanics of fluids and to cover adequately some of the more elementary technical applications." Some topics which are known to present difficulties to students have been discussed at considerable length, not in order to elaborate details but to reduce the difficulties. A number of examples are worked out in the text to illustrate the more important parts of the subject. These examples avoid the triviality often found in worked examples and should be really useful to the student. In addition, there are numerous examples for the student to work out, grouped at the end of each chapter.

Chapter I deals briefly with properties of fluids and hydrostatics, omitting the stability of floating bodies. There is also an excellent concise explanation of the units used in fluid mechanics, a point of weakness in many other books. In the treatment of "classical" fluid mechanics in the next two chapters the procedure adopted is to go as far as possible in pure *kinematics* (Chapter 2) before going on to dynamics in Chapter 3. This procedure helps to clarify the essential principles, and the student should have no serious difficulty provided he takes note of the authors' advice that only the earlier parts of Chapters 2 and 3 should be read at first. A particularly good point in Chapter 2 is the introduction to the use of the complex potential by consideration of the one-dimensional wave equation. The section on the momentum equation in Chapter 3 might have been improved by including at this stage some examples of *simple* applications. (There are such examples in other parts of the book, but they are not related very closely to this chapter.)

Chapter 4, on similarity and dimensional analysis, follows in brief the lines of the well known book by Duncan. The subject is not an easy one to learn and many students may find this chapter difficult. Chapter 5 gives a brief survey of the experimental techniques used in fluid mechanics. In the space available, it has only been possible to give an outline of the more important methods.

Chapter 6 is an excellent account of boundary layers and related topics. It is 150 pages long and forms an important part of the book. Methods of calculation are given for both laminar and turbulent boundary layers and there are numerous references to original papers. In a short section on mixing-length theories, suitable cautionary remarks are included to warn the reader against attaching too much importance to these theories. A notable feature of the chapter is the inclusion of recent work on the mechanism of transition.

Chapters 7 and 8 deal with flow in pipes and in open channels. In going on to these chapters from the earlier ones there is a noticable change of emphasis, possibly due to a change of author, towards the more empirical approach of hydraulics. The statements made in Chapters 6 and 8 about the thickness of the laminar sub-layer are not exactly consistent, but since this thickness cannot be exactly specified the inconsistency is not important. Some readers may find difficulty in the discussion of critical depth in a channel, but this is never an easy subject to explain.

Chapter 9 is concerned with the flow of compressible fluids. In the section on the dynamical and energy equations, the authors have taken considerable trouble to avoid the inconsistencies and loose statements found in many other books. Unfortunately the order of presentation makes this section difficult to follow, and there is a seriously misleading statement on p. 475, "the energy equation . . . . holds for the steady adiabatic flow of an inviscid fluid." In all other respects Chapter 9 is very good, except that in some places it may not be immediately clear to the reader whether viscosity has to be neglected or not.

Chapter 10 deals with oscillations and waves and Chapter 11 with forces and moments on bodies in a stream. The latter is important for students of aeronautics; it includes an outline of aerofoil theory in two and three dimensions. It is good to see that an outline of slender-wing theory is included, in addition to the classical lifting-line theory. A minor criticism is that in most of this chapter the fluid is considered to flow from right to left, whereas in the remainder of the book the flow is generally from left to right.

The last two chapters deal with pumps and turbines and with propellers, fans and windmills. In the section on dimensional analysis of pumps and turbines there is a tendency to obscure the simple fundamental principles by paying too much attention to the particular forms of dimensionless parameter that are used by practising engineers. Also, it is not explained why constancy of the ratio of head to diameter is not a necessary condition for similarity. In discussing pumps and turbines, there is a tendency to use unnecessarily terms such as "tailrace" and "penstock" which may be unfamiliar to some readers. The subject of propellers is introduced at first using the geometrical approach favoured by naval architects, but the blade element and vortex theories familiar to aeronautical engineers are discussed later.

The exceptionally good parts of the book are those dealing with "classical" fluid mechanics and with boundary layers. The chapter on compressible flow is also good, but perhaps rather shorter than some aeronautical readers would like. The other subjects are adequately treated but are not outstanding. The references to original papers are well chosen and will be sufficient for most needs. There is a satisfactory index and the book seems to be remarkably free from errors and misprints.

The book fills a gap in the literature of fluid mechanics that has been a serious one. It should be of great value, both to students and to practising engineers.—W. A. MAIR.

PRINCIPLES AND PRACTICE OF AIRCRAFT ELECTRICAL ENGINEERING. *H. Zeffert. George Newnes, London. 1960. 726 pp. Illustrated. 90s.*

This book, by the Chief Electrical Engineer of one of the leading aircraft manufacturers in this country, gives an extremely comprehensive account of the electrical and electronic systems associated with current British aircraft. It deals adequately with equipment which is used in these systems and states the environmental and other conditions

under which such equipment will operate in a modern aircraft. Ignition and engine starting systems are also dealt with.

The first chapter will show the younger reader the growth in the use of electricity on aircraft from the early thirties, when 100 to 200 watt systems were the order of the day, until the present when many aircraft carry a total generator capacity of over 200 kilowatts.

In logical sequence, the author outlines the climatic and environmental conditions which govern the design of all airborne accessory equipment, details the prime movers which drive the generators and describes in detail some of the variable-ratio drives, which are necessary with a variable-speed prime mover if a constant-frequency a.c. supply is required for aircraft services. The point could be made that such drives can also be worth while with d.c. systems, particularly when the prime mover has a very wide speed range.

One of the most important chapters is Chapter 4, which discusses Systems Selection and in which the author very fairly sums up the pros and cons of the various systems. It seems obvious that there is no easy path to system selection. As pointed out, "the problem is a complex one" and it is opportune that reference is made to the necessity for adequate reserve power to meet future development of the aircraft. This is vital when new and desirable power-consuming equipment becomes available a few years after an aircraft is accepted into service.

D.c. and a.c. generating systems are described in Chapters 5, 6 and 7. While these chapters provide much detail, the examples of alternators in Chapter 6 refer only to machines of American design. Some reference to British brushless alternators would have been desirable, since the rotating rectifier brushless alternator was a British invention. In addition, Britain led the world in the development of frequency-wild a.c. systems.

Several chapters are devoted to wiring and components used in aircraft circuits and to secondary power systems, including batteries.

Chapter 15 deals with the all-important subject of circuit design and the protection of the circuit, and the available fuses and circuit breakers are covered.

When electric engine starting is employed and a self-contained starting system is a requirement, the electrical system must be designed to meet this demand. Chapter 17 shows typical electric starters and starting circuits for jet engines and follows this by outlining some of the more modern non-electric starting systems which show a weight saving over electric systems.

Ignition equipment for both piston and jet engines is briefly described and other engine electrical components are mentioned.

Electric de-icing systems are important insomuch that they are consumers of large amounts of electrical energy, and the author rightly gives adequate attention to these systems, which do not require constant-frequency a.c. On the other hand, powered flying control motors require a.c. at constant frequency and, again, represent a heavy load on the system.

Finally, instrumentation and avionic equipment, typical of present-day thinking, is described and reference is made to the power requirements of this apparatus.

This book is a work of major importance and it is believed to be the first of its kind to be published in Britain. It will be welcomed by the electrical design staff of aircraft companies, by R.A.F. personnel engaged on electrical maintenance work and by electricians employed by airline operators throughout the world.

As Sir George Edwards points out in the Foreword, the safety and reliability of the modern transport aircraft depends as much on its systems as on its basic design.

Well-written and illustrated, the only criticism is hardly the fault of the author. Works of this size take several years to write and, accordingly, cannot be as up-to-date as the author would no doubt wish. It is suggested that in subsequent reprints, reference should be made to the many solid-state devices now finding favour on modern systems for voltage regulation, protection and static inversion, to the new types of alternators and to frequency-conversion systems by the use of which variable-ratio drives may one day be eliminated.

Also when reprinting, the text requires some revision on pages 105 and 382. In both cases, there is an error in the speed quoted for an a.c. machine with a given number of poles and a given frequency.—R. H. WOODALL.

PROCEEDINGS OF THE 10TH INTERNATIONAL ASTRONAUTICAL CONGRESS. LONDON 1959. *F. Hecht* (Editor). *2 Vols. Springer, Vienna. 1960. 504 pp. and 441 pp. Illustrated. £19 11s. 6d.*

Although eighty papers were presented at the 10th International Astronautical Congress, only seventy-two are printed in full in these volumes, the remaining eight being represented by either abbreviated versions or summaries. Over half of the papers emanated from the United States, no other country contributing more than five.

Nearly twenty-five per cent of the papers are devoted specifically to artificial satellites and a few of these give some important scientific information. D. G. King-Hele gives an excellent description of the methods used to determine air density and the earth's gravitational field from satellite orbits and reviews the results; H. K. Paetzold and H. Zschorner correlate the variable accelerations of satellites with changes in upper atmospheric conditions; V. G. Istomin gives results obtained from the radio frequency mass spectrometer aboard Sputnik 3; and V. I. Krassovasky and his associates discuss the large electron fluxes discovered by Sputnik 3. G. V. Groves and M. J. Davies give a method of analysing satellite observations assuming the orbital elements are arbitrary functions of time. This work is rather academic, except for the treatment of aberration and refraction effects, which have not previously been discussed.

Propulsion does not receive as much attention as in previous years. R. H. Boden surveys recent developments in ion rockets and G. Kuskevics discusses the efficiency of ion sources, giving an extensive bibliography of surface ionisation. Other papers deal with nuclear and magnetic propulsion. More conventional rockets are dealt with by H. L. Thackwell, who outlines the development of solid fuel rockets for the final stages of the American satellite launching vehicles.

As usual, fluid dynamics is not forgotten. The boundary layer flow of a compressible, electrically conducting fluid in the presence of a magnetic field is the subject of two papers. L. G. Napolitano and A. Pozzi consider the boundary layer on a flat plate and P. S. Lykoudis and J. P. Schmitt investigate unsteady two-dimensional stagnation point flow at hypersonic speeds. S. M. Scala gives a comprehensive review of hypersonic ablation and W. R. Warren discusses experimental studies of re-entry aerodynamics.

Other papers cover a variety of subjects. Twelve papers are devoted to the biological and medical aspects of space flight and three to the effects of meteor impacts. D. R. Chapman studies the corridor through which manned space vehicles must be guided to achieve successful re-entry and R. N. A. Plimmer contributes a useful paper on the fuel requirements for inter-orbital transfer. R. R. Newton discusses Doppler tracking of objects in the solar system; this is an important technique when applied to satellites, forming the basis of the Transit navigational system.

The papers are of a higher scientific standard than in previous years, but the volumes can be criticised on several points. There are far too many misprints, giving the impression that several authors never even read the proofs of their papers; and Volume II would benefit by the addition of an index or a list of contents. The inclusion of only the abstracts of certain papers is greatly to be deplored. Knowing that a certain paper was given at a particular congress one expects to find it in the published proceedings. It is no consolation to the majority of readers that some of the Russian works treated in this way have already been published in Iskusstvennye Sputnik Zemli—especially when this is not stated. The volumes are well printed, as one expects for such an exorbitant price.—G. E. COOK.

THE BRITTLE FRACTURE OF STEEL. *W. D. Biggs. Macdonald and Evans, London. 1960. 420 pp. Illustrated. 70s.*

The dust cover states "This book is designed to provide engineers, metallurgists and others with a comprehensive review of the present knowledge on the brittle fracture behaviour of structural steels." This claim is a fair description of the book provided that structural steels are taken as excluding high tensile steels.

It starts with a satisfactory introductory chapter which, among other matters, defines brittle and ductile fractures. The next chapter lists a number of the more important failures in ships and in engineering structures on land. The next four chapters deal with the Mechanical Aspects of Fracture, Effect of External Conditions and Metallurgical Variables, and the Nucleation and Propagation of Fracture. The remainder of the book covers Mechanical Tests, Correlation of Test Results, the Effect of Metallurgical Variables on Notch-Bar Tests, Welding and Residual Stresses. There is a final useful chapter headed "Summary" which is a discussion of the subject with proposals for research. The book is written mainly from the viewpoint of a metallurgist and metallurgists will find it easier to read than will engineers. There is no doubt that the people who will find this book most valuable will be those who are carrying out research into the brittle fracture of mild and low alloy steels, since it assembles and summarises in a most useful way the vast literature on the subject. For such persons the book will be a necessity. The engineer who is interested in preventing brittle fracture will find the book very solid fare but, if he perseveres, will find what is known of the subject within the book's covers. The aeronautical engineer will find very little in the index on alloy steels, although there is more in the book than would appear from the index. The brittle fracture of very high tensile steels is not seriously discussed. There is oddly enough a section on the brittle fracture of cast iron, though the book is on steels. The author seems to dismiss rather lightly the effects of irradiation on the shells of nuclear reactors.

The book is well printed and illustrated and can be thoroughly recommended to people who are interested in the brittle fractures of steels used in large engineering structures such as ships, bridges and storage tanks. It will also give useful background knowledge to people interested in the fracture of both alloy steels and body-centred cubic metals other than iron.—J. H. RENDALL.

AERODYNAMICS FOR ENGINEERING STUDENTS. *E. L. Houghton and A. E. Brock. Arnold, London. 1960. 440 pp. Diagrams. 45s.*

This book is intended for students of Aeronautical Engineering and adequately covers the requirements of the Higher National Certificate and Diploma Courses, Parts I and II of the University of London B.Sc.(Eng.) Degree, and the first three years of the Hives Council Diploma of Technology. Without hesitation, this is a "number one" book for engineering students. The classical books of Milne-Thomson, Piercy, Duncan, for example, are admirable for mathematicians or physicists, but lack the practical applications, clear sketches and precise numerical uses, for which an engineering student is continually seeking. In many theories there are steps which can be unmistakably illustrated in bold outline, and throughout this book excellent sketches are a welcome feature. The chapters on Finite Aerofoil Theory and Aircraft Stability and Control are particularly admirable in this respect.

Each chapter begins with a logical development of theory; notation, symbols and units are well-defined and worked numerical examples are given to emphasise that these theories are exceedingly useful. Exercises with answers are supplied with each chapter. Chapters 7 to 9 on propulsion and performance are well stocked with up-to-date examples including the rocket motor, rocket missile, and the "Hovercraft." A short Chapter 5 on "Wing and aerofoil section geometry" is well chosen. Chapters 10 and 11 deal with two-dimensional fluid flow and logically work through stream function, circulation, velocity potential, complex potential function and conformal transformation, after the style of Glauert. So many aerodynamics books plunge into velocity potential and complex potential function in the first paragraph, which is fatal to most engineers!

It is felt that a separate chapter on Dimensional Analysis and its many applications would be better than three sections in three separate chapters. A brief outline of the three basic normal shock wave equations could be included with advantage in Chapter 4.—D. B. SWINBANKS.

HYPERSTATIC STRUCTURES. Vol. II. *J. A. L. Matheson and A. J. Francis. Butterworth, London. 1960. 282 pp. Diagrams. 60s.*

The first volume of *Hyperstatic Structures* was reviewed in the October 1959 JOURNAL, and covered the title field in the manner of a textbook, illustrated by the normal proportion of worked examples. Volume II completes the work and is both complementary and supplementary to its companion.

The pattern of this second part is that each chapter largely follows the field of the corresponding chapter of Vol. I. Within the chapters each section begins with a brief recapitulation of the appropriate theory, then goes through one or two worked examples, and finally sets out the problems for solution, which are mainly from University engineering papers. The balance between these three divisions is excellent, and this volume certainly adds to the effectiveness of its predecessor. Moreover, it will admirably stand on its own as a revision textbook.

The presentation, following that of Vol I, is excellent; but, also following Vol. I., it remains a book confined to frameworks. Even civil engineers have to design shell structures these days! There is an interesting divergence of opinion between the dust cover and the title page as to the description of the senior author.—K. H. GRIFFIN.

THE HERO: CHARLES A. LINDBERGH: THE MAN AND THE LEGEND. *Kenneth S. Davis. Longmans Green, London. 1960. 445 pp. Illustrated. 30s.*

This is an outstanding biography which studiously avoids that all-too-common failing of badly-written books of this type: the portrayal of its subject as a man with more than his share of good qualities and fewer than would be human, of bad. Mr. Davis—who has been a journalist and, more recently, with the U.S. State Dept.—has done more than write a most effective, analytical biography of one of the most publicised figures of the first half of the twentieth century.

His book is also a frightening study of the power of the Press in the modern world. He shows all too clearly how the commercial interests of newspapers can exploit happenings with news appeal in such a way that the whole course of history is influenced by events and individuals which might otherwise have seemed quite unimportant and would probably have had little or no effect upon it. This book will confirm in the minds of many the cynical reflection that it is not so much actual achievements or the quality of individuals, organisations or their products which count. Too often the criterion of fame or success seems to be the way in which the story is told to the world, largely through the Press.

This is not to say that Lindbergh did not deserve a great deal of fame for his remarkable non-stop trans-Atlantic solo flight from New York to Paris in 1927. He undoubtedly did. It was a tremendous achievement which only an exceptional pilot flying an aircraft outstanding for its time could have accomplished. In particular, Lindbergh proved himself to be one of that select band of pioneer long-distance pilots of the 1920s who proved themselves capable of prolonged instrument flying under the most adverse conditions of weather and fatigue with the help of little more than a turn indicator.

Lindbergh was an unknown young air mail pilot of 25 when he flew the Atlantic. Overnight he became a World figure. The Press—and particularly the American Press—seized upon this event and built it up into the biggest news story of all time. They enmeshed Lindbergh himself and created around him what soon grew into almost a new cult: that of a national hero personified, a kind of "shining symbol" of American youth, manhood and civilization. The extraordinary thing was that this illustration of the power of publicity was sustained not just for days or months, but for

years. Having created their public image, the Press found that it paid them to maintain it. They sustained their picture of a national hero so persistantly that the object of this national adulation, in spite of a modesty and self-restraint remarkable in one so young, was in the end overwhelmed by it and was even hounded from his own country in his attempts to win back some privacy for himself and his family. After the kidnapping and murder of his first child—which resulted directly from the publicity he had received—Lindbergh was forced to emigrate first to England and later to France.

Although the effect on Lindbergh of all this was to have unfortunate consequences later, the volume of public interest in aviation which the press generated in the United States as an essential part of this campaign proved to be of great benefit to American aviation. Indeed, it is not too much to say that America's lead in the air in the years since the Second World War sprang directly from the remarkable development of their airline and aircraft manufacturing industries which was sparked off by Lindbergh's flight in 1927.

In discussing Lindbergh's reactions to all the publicity showered upon him, Mr. Davis fairly sets down both his hero's point of view and that of his many detractors—and, inevitably, there were many of a man who lived in such a glare of public attention. But, whatever the importance one may attach to the argument that Lindbergh made things unnecessarily difficult for himself by a policy towards the Press of secrecy about himself which only served to stimulate their interest, one cannot but sympathise with an individual who, because of the Press, soon lost much of his personal freedom.

During the years before the War, when Lindbergh lived in Europe and was engaged in the advanced medical research in which he had become interested, he seems to have come increasingly under the influence of the Nazis and to have been persuaded that their political system must inevitably prevail against the "degenerate democracies." His reputation as an air expert was cleverly used by the Germans to increase the effectiveness of the threat of their rearmament in the air.

They convinced him of their technical ascendency and then relied on him, through his many personal contacts with those in influential positions in the West, to undermine confidence in those countries in their own ability to match German aviation progress. This strategem succeeded all too well and there is reason to believe that Lindbergh played an important part in increasing the effectiveness of the Axis's "War of Nerves" which preceeded the actual outbreak of hostilities.

When war came, Lindbergh returned to the United States and continued—but with even greater effect—to undermine confidence in America in the ability of the Western Powers to successfully resist German aggression. He became the leading political figure in the Isolationist Movement and was the rallying point for the strong opposition to Roosevelt's policy of helping the Allies by every means short of actual participation in the War which continued right up to Pearl Harbour.

We have, for these reasons, no cause to like Lindbergh in this country: apart from any help which he gave to our enemies, his activities in 1940 and 1941 did more than those of any man to dissipate Britain's foreign investments before the Americans introduced Lease-Lend. Loss of these investments has been one of the important causes of our economic difficulties since the War. Even so, few Englishmen, with their respect for individual privacy, will not feel sorry for this talented man whose destiny was so largely shaped by the gross inhumanity of one of the most important institutions of the Western way of life. The very weaknesses which are inseparable from the true strength of a free Press fashioned something which, in the end, could not be controlled and came near to turning against the very system which had created it.—PETER W. BROOKS.

GHOST SHIP OF THE POLE. *Wilbur Cross. William Heinemann, London. 1960. 306 pp. Illustrated. 25s.*

This is a book which would make good reading for all interested in aeronautical history, airships, polar exploration and human psychology. Heroism and depravity are both depicted, and the book also shows how what might be termed "aeronautical politics" bedevilled the whole affair. If this book is accurate, and certainly its author seems to have done his best to make it so, the Italian airships were sacrificed because of the jealousy of the aeroplane school. Marshal Balbo, for example, cuts a very poor figure. Even other Italian airship men such as General Crocco appear to have tried to frustrate Nobile.

The book tells of Nobile's earlier days, and something of the Norge flight over the North Pole in 1926. The Norge was a good ship, and Nobile was a good designer of semi-rigid airships, but the late Major Scott had to land the ship at Pulham, and General Riiser Larsen at Oslo. The reason for this was that the ship had not been "ballasted up" properly and in both cases they tried to land too "light." But Colonel Nobile (as he then was) learnt from experience and after this he made good landings.

When the Italia flew from Milan to Stolp, in Germany, every type of weather was encountered and the crew under Nobile, now a General, handled the ship with great skill, otherwise they could never had won through. The story of this flight makes excellent reading, and the ship was certainly tried to the utmost. When they reached Svalbard and their Northern Base, the Norwegians came to the rescue as the Captain of the base ship did not consider, apparently, that his men should be used as a handling party.

Before this the airship had been moored to a mast at Vadsö. Here she had to face blizzards, which frequently swung her round 360°. The mast head was the same as the Pulham mast of the late Major Scott, and helped to make this expedition possible. Today all airships use the mooring mast and the basic design is still the same as Scott's, which was used first by HMA R33 in February 1921. This book brings out the usefulness of the mast.

The two flights, one of 8 hours and the other of 69 hours are both described, and then comes the last flight when the North Pole was once again flown over and the airship crashed. This flight is recounted in great detail, so it is almost possible to imagine oneself on board the airship. The characters of the crew stand out, and next to Nobile, Dr. Malgrem the Swedish Meteorologist had the greatest responsibility. They met with vile weather, and it looks as if the final crash might have been caused by the blowing off of too much gas when she flew for a short time above the fog and in bright sunshine. Perhaps one or more of the valves froze open, for there was trouble with barrage balloon valves in the winter of 1940 even at 5,000 ft. or less above this country.

When the crash occurred the control car alone became detached from the rest of the ship which bounded in the air carrying six of the crew who were never seen or heard of again. Owing to the muddled arrangements it seems to have been almost a miracle that there were any survivors at all. Humanly speaking it was the radio worked by that splendid man Biagi which saved their lives. The Italians on the Citta da Milano seemed to have done very little for their countrymen, and everything had to be referred to the dictators in Rome. It was the Norwegians, Swedes and Russians who were the real heroes, and that great man Amundsen gave his life looking for them.

The way that Nobile was treated was to my way of thinking abominable, and even in the worst circumstances he stood out for Christian as opposed to pagan principles. Had Nobile been backed by the Italian authorities and given a fair chance things might have turned out very differently. He was first and foremost a designer and trial pilot and was never meant to be the leader of a Polar expedition. It might have been an international undertaking, and Nobile if he had been left alone and properly supported could have achieved great things. As it was he had an almost hopeless task, for he had not only to contend with the worst possible weather, and all kinds of almost unknown hazards, but the enmity of human beings.

This well illustrated and indexed book of 300 pages brings all this out and deserves to be read. Without hiding his weaknesses it surely vindicates General Umberto Nobile, who it is good to know is still with us.—VENTRY.

NOISE REDUCTION. *L. L. Beranek (Editor). McGraw-Hill, New York. 1960 752 pp. Illustrated. 112s. 6d.*

Most of the material in this book comes from lecture notes prepared for two-week summer schools on noise reduction presented at the Massachusetts Institute of Technology in 1953, 1955, 1957 and 1960.

The first of the four parts into which the book is divided deals with the elements of acoustics and acoustical measurements. This style is too chatty for your reviewer's taste, but this section contains a great deal of good advice to the newcomer to the field. Part two deals with the basic questions of noise control: sound propagation in the atmosphere, sound in enclosures, sound transmission through structures, acoustical materials, mufflers and vibration control. A good account is given of these problems, the results and techniques available. This is followed by a short part three on the difficult questions of criteria for comfort, annoyance and physical damage and the book ends with an interesting series of chapters on practical noise control in which the case histories of various problems are given.

It will be seen that an attempt is made to cover a very wide field; in fact the object of the summer schools was to take a graduate trained in almost any field of engineering and lead him from the elements of the subject right up to an appreciation of some of its most difficult problems. This is an almost impossible task and such a course is almost sure to be patchy and will leave the student with much reading to do. The same will be true of a book produced from the lecture notes.

In the first part, the more mature reader will be irritated by the assumption that he needs a section devoted to the sine wave and exclamation marks to drive home the difference between a progressive wave and a standing wave, and disappointed that the small amount of mathematics necessary to understand clearly the difference between the near field and far field is omitted. Later, he will be impressed by the considerable experience which obviously lies behind the chapters on measurement but slightly offended by the advice that before taking a measurement he should examine his apparatus to make sure it has not been dropped. There is a great difference between what can be said in the lecture room and what should be written in a book.

Subsequently, however, there are only occasional lapses into this colloquial style and parts two, three and four can be recommended to anyone interested in the problems of noise reduction. This is to be expected, since once the preliminaries are over the authors set out to impart their combined knowledge and experience, and all of the 19 authors being prominent men in their fields, the result is bound to be worth reading.

An excellent feature of the book is the large number of references at the end of each chapter. Some of these might be difficult to obtain, but nevertheless there are enough to enable the reader to follow up any point in which he is particularly interested. In his preface the editor emphasises the need for further reading and quotes three references in particular. To these three should be added (a curious omission) a good modern textbook on acoustics.

In general, the book is well produced although your reviewer found two mysterious changes of type. It is to be regretted that it is rather expensive.—R. E. FRANKLIN.

AGARD AERONAUTICAL MULTILINGUAL DICTIONARY. *Edited by G. H. Frénot and A. H. Holloway. Pergamon, Oxford. 1960. 300 pp. 8 Languages. £7.*

A few nations have led the way in providing the background of knowledge on which the science of aeronautics is based, but the desire of other nations to learn the know-how and, reciprocally, the ability to read the contributions from the newcomers in the field, has indicated the need for the present Agard publication. It does not, however, yet include any terms dealing with missiles or satellites.

This dictionary is basically a glossary of aeronautical terms in English, French, German, Spanish, Italian, Dutch, Turkish and Russian, based on British Standard 185, which is a Glossary of Aeronautical Terms. Each British definition has been translated by representatives of the NATO nations in their own language; in addition, Spanish friends are responsible for the Spanish version and the Ministry of Aviation in the United Kingdom for the compilation of Russian terminology. It should be helpful to expert groups concerned with documentation and welcomed by persons connected with aeronautical research and industry in the respective countries. At first, they may feel a little irritation at being confronted with the many subdivisions of the book and no hint in the form of a Contents list as to what even the main fifteen divisions are. The user has to look into the book to find this out, a matter that could easily be rectified. Nevertheless, the compilation has been worthwhile and in some cases the translators have improved considerably on the original B.S.I. Glossary; for example, in English a rocket contains all the matter for producing a jet, whereas the Italian definition refers to a motor and the gases produced by chemical reaction.

At the end of the book are indexes of the various terms in each language, the English being much the longest. The others could be improved as the terms are usually indexed only under the first noun; for example, weathercock stability is indexed under both words, but the French index contains only *stabilité* and not *girouette;* again, *angolo di rollio* is not indexed under *rollio;* and so on. It is also suggested that existing common usage of British terms should be adopted even when the B.S.I. Glossary does not conform; for example, turbojet and turbofan are single words and not hyphenated and an intermittent jet is called a pulsejet. Perhaps also, a loose-leaf book, such as this is, might well have stronger flexible connections between its very strong spine and the hard-back covers. In all other respects the production is first class—J. L. NAYLER.

PRINCIPLES OF CONTROL SYSTEM ENGINEERING. *V. del Tor and S. R. Parker. McGraw-Hill, London. 1960. 686 pp. Diagrams. 112s. 6d.*

Books on the principles of control system engineering appear with monotonous regularity and the vast majority are based on lecture notes which the author has found, in practice, to be satisfactory. This book is no exception and while one is tempted to doubt the assertion that the book fulfils a long standing requirement for a text which furnishes an exposition of the various methods of analysis and design and also describes their inter-relationship, it is felt that it does provide rather more mathematical justification than is usual, as well as being laced with practical examples and touches on the newer topics such as self-adaptive control systems.

The first three chapters (Part I) consist of the usual terminological and mathematical introduction and the treatment is thorough and readable. Part II is an exposition of what is called the "Time-domain Approach" and is a study of the straightforward differential equation approach to servo systems. This is often cumbersome but with the availability of Analogue Computers can sometimes, by virtue of its completeness, be the most useful approach. Part III, laying out the usual frequency response methods, is similar to other books on the subject but contains a wealth of correlation and explanation. The stability aspects of this Part are also rather more complete than usual and some interesting aspects of various contours are brought out in the examples. Part IV concentrates on the Root-Locus approach leading up to a chapter on the synthesis of compensation transfer functions with R.C. networks. This is a highly important subject in practice, and the quality of the book is improved by a more than usually competent treatment. Computers, both analogue and digital, are discussed in Part V and, while an appreciation of the function and usefulness of analogue computers is essential in servo work, it is not quite so certain that the chapter on digital computers is necessary. Under special topics there is an introduction to the ideas of self-adaptive control

systems and this is the first time the reviewer has seen textbook reference to this subject. The definition of such a system is broad and loose and would not satisfy the purist, but the chapter does give a description of the type of thinking in this field and would be useful to a student.

In general, then, this is considered to be a much better than average book on the principles of control system engineering and can be recommended to the meticulous student or to the person who requires a deep understanding of the problems involved.—JAMES F. FOODY.

STRESSES IN SHELLS. *Wilhelm Flügge. Springer-Verlag, Berlin. 1960. 499 pp. Diagrams. DM. 58.80.*

The theory of shells is a subject which has a truly international flavour but books devoted entirely to the subject, as distinct from chapters in a book on elasticity, are rare.

Professor Flügge's book, following closely on the publication of the translation from the Russian of Novozhilov's *Theory of Thin Shells*, is therefore very welcome and to those familiar with Flügge's work in German, *Statik und Dynamik der Schalen*, its arrival has been eagerly awaited. It should be emphasised here that the book is not a translation of the German book but contains a lot of new material and a representation of some of the work included in the earlier book. Again, some subjects dealt with in the German book have been omitted from the present work.

With so few books on a subject available, some comparison between the works is inevitable and the reader cannot but help being struck by the difference in approach adopted by writers of different nationalities.

The first impression formed after reading the book is one of orderliness and thoroughness and, although the English is a little naïve in places, it is adequate and indeed refreshingly direct and forthright.

Throughout the work there is a happy blending of explanation and mathematical expression and the work is illustrated with 244 figures of great clarity. In the preface the author appears to be a little apprehensive about the mathematics he has included but an honours graduate in either Engineering or Physics who has studied Applied Elasticity should have no difficulty in following the mathematical arguments, which are most clearly explained.

There are seven chapters, together with an appendix dealing with the forces and deformations in circular rings. The first six chapters are concerned with membrane and bending stresses while the last deals with the buckling of shells.

The first chapter gives the basic general properties of stress systems in shells and here the reader has a concise introduction to, or revision of, the subject according to his knowledge. Co-ordinate systems are described but, surprisingly, curvilinear co-ordinates and a general discussion of the theory of surfaces has not been included.

The next three chapters describe the membrane theory of shells, beginning with shells of revolution followed by cylindrical shells and shells of arbitrary shape. The treatment of the membrane theory is lucid although it is a pity the author did not emphasise the subtle difference between a pure membrane and a momentless shell. Also, a fuller discussion of the implications of the vexatious boundary conditions would have been welcomed.

The bare titles of these three chapters cannot convey the wide variety of subject matter covered by them. In shells of revolution, cases of axial symmetrical as well as loading without axial symmetry are considered although, as usual, cases of unsymmetrical loading have been idealised. The chapter on cylindrical shells includes a discussion of tubes and pipes, barrel vaults, polygonal domes and folded structures, all subjects of intense current interest.

The chapter on direct stresses in shells of arbitrary shape is most interesting, particularly as the stresses in paraboloid, elliptic paraboloid and hyperbolic paraboloid shells are discussed. Here again, although the boundary conditions are mentioned briefly, the implications of the now time-honoured assumption that the elliptic type shells are supported by arches which accept only a shear, but not a thrust, are not sufficiently discussed. The chapter concludes with a valuable analysis of the membrane forces in affine shells.

Chapters 5 and 6 concern the bending of circular cylindrical shells and the bending stresses in shells of revolution respectively. Naturally enough, in view of the development of shell theory, no mention is made of the bending stresses in shells of arbitrary shape. The theory of bending of circular cylindrical shells is developed clearly to the stage when a simplified workable approximation is derived and the secondary stresses, which are ignored in the membrane theory, are taken into account. A discussion of bending theory applied to barrel vaults, cylindrical tanks, anisotropic shells and folded structures follows, including a brief outline of the important case of a shell reinforced with rings and stringers.

The bending stresses in shells of revolution are carefully developed to the stage when a simplified set of equations expressing the elastic law are obtained. Again, each step is explained and the reader is led gently to the final simplification of the axially symmetric, constant thickness shell subjected to an axially symmetric load; this is followed by an analysis of spherical shells, shells having a meridian of arbitrary shape and conical shells.

For a shell of revolution, the coefficients of all equations are independent of the angle in azimuth; therefore, when all the stress resultants and displacements are expressed as Fourier series in this angle, the relevant equations are reduced to a set of ordinary differential equations and the chapter concludes with the solution of these equations for spherical and conical shells.

It is strange that conoidal shells, which were mentioned briefly by the author in *Statik und Dynamik der Schalen* are not considered here and it is to be hoped that it will find a place in a later edition.

The seventh and last chapter is devoted to the buckling of cylindrical and spherical shells, but only six of the 72 pages are concerned with spherical shells. The buckling of cylindrical shells is discussed for a variety of loading actions and includes a consideration of the effects of imperfections of shape; an interesting introduction to the non-linear theory of shell buckling is included. There is nothing essentially new in this chapter but it does give a good up to date summary of cylindrical shell buckling theory.

Readers interested in the stress analysis of shells will not necessarily be interested in the buckling of shells and, in view of the high price of the book, it is a pity the author did not omit this chapter and use it to form the nucleus of a book on shell buckling theory, particularly as with the present rapid advancement of shell theory a later edition of *Stresses in Shells* must inevitably be expanded.

All but a few references to published papers are omitted from the text but an interesting bibliography is included at the end of the book which, under each chapter heading, lists most of the important papers in shell theory and forms a condensed history of the development of the subject.

The notation used is the one popularised by Timoshenko in his series of famous books on elastic theory, with the addition of the multiple "dot" and "dash" notation to denote differentiation of a function with respect to different variables. Although this notation may save space and time when writing down equations during a lecture, nevertheless, in the reviewer's opinion, it interrupts the continuity of thought when attempting to understand a subject from a book.

The publication of Flügge's book, following so closely on the heels of Timoshenko and Woinowsky-Krieger and Novozhilov's books, all in the English language, must give a fresh stimulus to the development of shell theory. A serious student of the subject will not be content unless he works with all these books beside him; if the reviewer were allowed one book on Shells only on a desert island, Flügge's book is the one he would choose and it can be

recommended unreservedly to students, research workers, and designers of shell structures.

The publisher is to be congratulated on his publication, which amounts to a work of art.—S. C. REDSHAW.

MONSTERS OF THE PURPLE TWILIGHT. *Ernest Dudley, Harrap, London. 1960. 218 pp. Illustrated. 18s.*

This is an interesting well-written story describing one aspect of the work of the Zeppelin airships during the First World War. Mr. Dudley must have taken infinite trouble to collect from both British and German sources the information on which his story is based. He outlines the early airship development in Germany achieved almost wholly by Count Zeppelin with the enthusiastic support of the Kaiser and with funds contributed by the public under the stimulus of national pride.

In 1914 Germany had a small number of Zeppelins, sufficient to form a serious striking force against which we had no aircraft with sufficient climb to reach them and no guns capable of hitting them except by remote chance. As time went on the strength of the potential airship attack and also that of the defence both increased, but the balance must have been greatly in favour of the airship for many months. The German Airship Command had no clear policy other than vague directions from the Kaiser, evolved after considerable doubt, that it was against the civil population of London that the attack must be directed in order to break national morale. Our defence therefore concentrated around London and the line of approach from the Wash which the airship captains found to be their most satisfactory landfall. Used as they were the airships locked up in England a number of men and guns which in the conditions at that time might have made a comparatively small difference on the Western Front. The effect on civilian morale was quite different from that intended. It did in fact, harden our determination and raised a fury against the frightfulness of the enemy. Had the balance in favour of the Zeppelins been used promptly in co-ordinated vigorous attacks against widely dispersed areas of munition production it would have been very difficult to counter and must have had far more effect. Bristol, Liverpool and Glasgow were well within the range of their newer ships which could, having dropped their bombs, run to a height at which they might drift home far above aircraft attack and probably with cloud cover.

The author makes no mention of the Zeppelin patrols over the North Sea which gave their Navy information, almost whenever they wanted it, about the disposition of British naval forces. By our great good fortune this patrol could not be done on the two days before Jutland when it might have had very serious influence indeed.

It was the duty of your present reviewer to develop the construction of our own non-rigid airships not only those for anti-submarine work, but also the larger "North Sea" type to have speed and endurance capable of giving to our own Naval Forces something equivalent to the Zeppelin Patrols. The cogency of the Naval demand for these ships left no doubt about the value of the Naval Zeppelins. Our defence gradually gained conclusive superiority and, especially after Jutland, the Zeppelin work faded completely.

The author is interested in the use of Zeppelins for their attack on the morale of the civil population and also in the difficulties and courage of the British pilots who shot them down. With this in mind he chooses a title which distorts Tennysons phrase "*Pilots* of the Purple Twilight" and writes up the horror and the heroism. He regularly refers to the British aircraft as "ridiculously fragile wire and canvas wooden planes." In fact those aircraft had been devised, designed and made with a skill and ingenuity which must be regarded as admirable if we remember how limited was the scientific knowledge available at that time.

There are in the text a number of mistakes of detail but they make no significant difference to the realism of the story.

The post-war development of the Zeppelins for civil purposes is a story of at least equal interest. Dr. Eckener's flight in "Graf Zeppelin" over Siberia to Tokio non-stop and on over the United States was a marvellous journey round the world. It was followed by the introduction of Zeppelins to the U.S. Navy and their eventual eclipse. If Mr. Dudley would write that story with equal care and skill—and with a more fitting title—we should have an interesting book indeed. Meanwhile the present book is interesting, easy to read and well worth reading.—T.R. C-B-C.

SPACE TRAJECTORIES. *Technical Staff of Radiation Inc. Academic Press, New York. 1960. 298 pp. Diagrams. $12.*

Describing himself as an astrophysicist, Charles A. Whitney, one of the contributors to this work, defines this as a physicist who knows too little astronomy to formulate any significant, yet soluble problems, or on the other hand as an astronomer knowing enough physics to distrust any other astronomer's interpretations of what he observes.

This doubtful classification is symbolic of the extremely involved field of space trajectory analysis. Old conventional methods of star-gazing are being superseded by new techniques involving electronic computers and, with celestial mechanicians becoming a dying race, the space age brings a host of problems hitherto beyond solution.

To obtain the most up-to-date information on this frighteningly involved subject, Government, Industry, and one Learned Society, in the shape of Advanced Research Projects Agency, Radiation Inc., and the American Astronautical Society, held a Symposium in December 1959 to exchange ideas among those most learned in this field and this book contains 20 of the papers presented.

Following a general survey of past accomplishments, future space programmes are discussed and the requirements for trajectory analysis are studied. The position of a satellite can now be determined by new methods to an accuracy of one-thousandth of a radian—one mile at 1,000 miles altitude. These methods of orbit computation by Vinti, Brower, Garfinkel, King-Hele and Brunner are explained and the design requirements of vehicle-borne computers are discussed in the light of the various methods of computation used.

Of considerable interest is a paper by Rudolf Herman on the influence of the atmosphere on re-entry trajectories. Hypersonic flow around various body shapes is analysed, and results are shown of wind tunnel experiments at $M=7$ concerning associated heat transfer problems.—M. D. HULL.

THE YEARS OF THE SKY KINGS.—*Corrections to January Review.*

I have just re-read my review of *The Years of the Sky Kings* on pages 145 and 146 of the February 1961 JOURNAL and I observe therein two points which I should have corrected. These are both on page 146. Line 6: the Friedrichshafen raid was made in 1914, NOT 1917. Lines 29-33: lines 29-31 stand as printed, but for lines 32-33 the following should be substituted:

"The prototype Sopwith Triplane was first test flown on 30 May 1916 and sent to Furnes for RNAS Service trials in mid-June 1916. Production delivery began late that year. From an RFC officer's diary I know the Triplane was at RNAS Dunkirk in mid-November 1916; and at St. Omer for RFC Service trials on 12 December 1916 on which date it was flown at St. Omer by R. Smith-Barry (of Gosport Special School of Flying fame). No. 1 Naval Sqn. had 16 Triplanes by mid-February 1917 and went into action in April 1917. No. 10 Naval Sqn. was at Droglandt aerodrome with Triplanes on 22 April 1917."

—NORMAN MACMILLAN.

Additions to the Library

Air B.P. Book of Flight Today. J. W. R. Taylor (*Editor*). Stanley Paul, London. 1960. 108 pp. Illustrated. 21s. Makes available to a wider readership articles from *Air B.P.*, the house magazine of the international aviation service. Illustrated in colour, includes "Who wants supersonic airliners?", "Aircraft automatic landing," "How aeronautical research is aiding technical education," "America's aircraft reactor programme," "Rockets and Satellites on Stamps," and the story of Icelandic air transport.

Die Gasturbine. J. Kruschik. Springer-Verlag, Vienna. 1960. 873 pp. Illustrated. £20 2s. 0d. (*In German*). The first edition, published in 1952 at £5 7s. 0d., was reviewed in the September 1953 JOURNAL (p. 608) as "a very adequate survey of the field" with a summary of published design and performance details and a valuable collection of data on heat resistant and other structural materials. It was pointed out by the reviewer, however, that the practising gas turbine engineer would certainly notice the omission of most of the information required on such topics as blading design, stressing and detailed performance calculations. This new edition includes a revision of the sections on turbine thermodynamics, thermodynamics of free-piston gas generators with turbine, their assembly and the various effiux shapes, the whole theory of turbine engines (axial and radial compressors and turbines), calculations for and construction of heat exchangers, strength calculations, gas turbines in conjunction with atomic power sources and the combined gas and steam cycle; but it still does not appear to meet the criticism made on behalf of the practising engineer. Although the book has nearly doubled its size and is beautifully produced, as are all the publications of the House of Springer, the new price must certainly be a deterrent to any but specialised libraries in English-speaking countries.

Embrittlement by Liquid Metals. W. Rostoker, J. M. McCaughey, and H. Markus. Reinhold Publishing Corporation, New York (Chapman and Hall, London). 1960. 162 pp. Illustrated. 64s. *To be reviewed.*

Enigma of Menace, The. Sir Victor Goddard. Stevens, London. 1959. 110 pp. 12s. 6d. An examination of the justification or otherwise of the use of the nuclear deterrent.

Flight Facts for Private Pilots. M. E. Tower. Aero Publishers, Los Angeles. 1960. 211 pp. Illustrated. $5. This publisher specialises in making things easy for the pilot, the navigator, the mechanic and all connected with Aviation. The chapter headings tend to make flying sound rather simpler than driving a car—What holds the Airplane up?; How to control the Airplane during Flight; The Power Plant and how to use it; Where am I? and so on; but in a country where the aeroplane as a private vehicle is not something at which to boggle, such a book is obviously more acceptable and more likely to be taken for granted than it is here.

High Speed Testing, Vol. I. Co-Chairmen: A. G. H. Dietz and F. R. Eirich. Interscience Publishers, New York. 1960. 112 pp. Illustrated. 38s. Nine American papers from a symposium on high-speed testing of materials, held at Boston, Massachusetts in December 1958 and sponsored by Plas-Tech Equipment Corporation. Subjects covered are testing of thermoplastics, plastics, rocket fuels, package cushioning materials and textile yarns, also stress relaxation, stress-strain properties of titanium, and metals at ballistic rates of loading.

Higher Plane Curves. George Salmon. Chelsea Publishing Company, New York. 1960. 395 pp. $4.95. **Curve Tracing.** Percival Frost. Chelsea Publishing Company, New York. 1960. 210 pp. $3.50. Both reprints of classics, first published in about the 1870s. The material in the reprints is dated 1879 and 1918 respectively and, from the fact that such reprinting has been undertaken at all, one would infer that there is still nothing better.

International Dictionary of Applied Mathematics. W. F. Freiberger (*Editor-in-Chief*). D. van Nostrand, London. 1960. 1173 pp. Diagrams. £9 7s. 6d. *To be reviewed.*

Kinetics, Equilibria and Performance of High Temperature Systems: Proceedings of the First Conference, Western States Section, The Combustion Institute, 1959. G. S. Bahn and E. E. Zukoski (*Editors*). Butterworths, London. 1960. 255 pp. Diagrams. 80s. Thirty-three papers by American authors read at the First Conference of The Combustion Institute. The Conference was primarily aimed at those who are engaged in performance calculations for high temperature systems. Groups of papers were devoted to input and output thermodynamic data, computer programming for output thermodynamic data and for standard engine performance parameters. Programmes for combustor and exhaust nozzle design and results of performance calculations were also included.

Lectures on Fluid Mechanics. Vol. II. Sydney Goldstein (*Editor*), with special lectures by J. M. Burgers. Interscience Publishers, New York. 1960. 309 pp. 50s. The second of four volumes (the first was on probability and related topics) which will cover the Proceedings of the Summer Seminar "Lectures in Applied Mathematics" held at Boulder, Colorado in June, 1957 and sponsored by the American Mathematical Society. The subjects include (briefly) kinematics, general fluid dynamics, electric and magnetic forces, boundary layers and turbulence, and the dynamics of inviscid gases; the readers are assumed to be "mature mathematicians."

Plasticity. E. H. Lee and P. S. Symonds (*Editors*). Pergamon, Oxford. 1960. 610 pp. Illustrated. 70s. Some thirty papers, with discussions, presented at the Second Symposium on Naval Structural Mechanics, sponsored by the Office of Naval Research and Brown University and held at Rhode Island in April, 1960. The Symposium was devoted to plasticity and was attended by British and Russian, as well as American, scientists.

Primer of Space Medicine, A. M. P. Lansberg. D. van Nostrand, London. 1960. 165 pp. Illustrated. 15s. *To be reviewed.*

Principles of Meteoritics. E. L. Krinov. Translated from the Russian by Irene Vidziunas. Pergamon, Oxford. 1960. 535 pp. Illustrated. 70s. This covers the study of the material composition, structure, morphological and physical properties of meteorites—the only extra-terrestrial matter falling from interplanetary space on to the Earth—together with the study of the conditions under which meteoric bodies move through the Earth's atmosphere and in interplanetary space. The production is of the photographed typescript variety (to speed up publication) and a publisher's notice apologises for the lowered standards of quality while blaming in part, unfairly it seems, the process of photo-lithography for this. There is also an explanation of the high cost.

Progress in Combustion Science and Technology. J. Ducarme, Melvin Gerstein, and A. H. Lefebvre (*Editors*). Pergamon, Oxford. 1960. 226 pp. Illustrated. 70s. Volume I of a series of review articles covering the field of propulsion and combustion as related to aeronautics. The six articles of this volume are Flow Visualization Techniques, by E. F. Winter; Chemical Analysis in Combustion Chamber Development, by B. Toone; Aerodynamic Influences on Flame Stability, by M. V. Herbert; Geometric-Optical Techniques in Combustion Research, by F. J. Weinberg; Flame Quenching, by A. E. Potter, Jr.; Ignition in Liquid Propellant Rocket Engines, by Edward A. Fletcher and Gerald Morell.

Spaceflight Technology. (The Proceedings of the First Commonwealth Spaceflight Symposium). Kenneth W. Gatland (*Editor*). Academic Press, London. 1960. 365 pp. Illustrated. 75s. *To be reviewed.*

Symposium on Nondestructive Testing in the Missile Industry. American Society for Testing Materials. Philadelphia. 1960. 71 pp. Illustrated. $2. Contains seven of the eight papers (all by American authors) presented at the Symposium in San Francisco in October, 1959. Subjects covered are radiography of rocket motors, mobile field testing, high-energy radiography, radiography of weldments, ultrasonic inspection of adhesive-bonded aluminium sandwich, ultrasonic detection of fluid contamination, and ultrasonic standards.

Reports

NOTE—It should be understood that while most of the undermentioned items are available on loan to bonafide inquirers, the Society is not agent for the sale of any of them. The great majority of the reports are "unpublished" and are not, therefore, obtainable through booksellers or other agents. Notable exceptions are the R. & M. and C.P. series which can be bought through Her Majesty's Stationery Office.

AERODYNAMICS

BOUNDARY LAYER *see also* STABILITY AND CONTROL
WINGS AND AEROFOILS
TESTING AND INSTRUMENTS
PROPELLERS

Boundary layers with suction and injection. A. H. Craven. C.o.A. Report 136. *Sept.* 1960.—(1.1.5×1.1.6).

Heat transfer and skin-friction measurements at a Mach number of 2·44 *for a turbulent boundary layer on a flat surface and in regions of separated flow. G. E. Gadd* et al. *R. & M.* 3148. 1960.—(1.1.3.4×1.1.4.4×1.9.1).

Entrainment in the turbulent boundary layer. M. R. Head. R. & M. 3152. 1960.—(1.1.3.1).

Similar solutions for the compressible boundary layer on a yawed cylinder with transpiration cooling. I. E. Beckwith. N.A.S.A. T.R. R-42. 1959.
Heat transfer and skin friction parameters obtained from exact solutions to the laminar compressible boundary layer equations for infinite cylinders in yaw are presented. The effects of transpiration cooling, Prandtl number, pressure gradient, wall temperature, and viscosity relation were investigated.—(1.1.1.4×1.9.1×1.10.1.1).

The momentum integral equations for three-dimensional laminar boundary layers in incompressible flow. M. G. Hall. A.C.A. Report 62. *Nov.* 1959.—(1.1.1.1).

COMPRESSIBLE FLOW *see also* LOADS
THERMO-AERODYNAMICS
WINGS AND AEROFOILS
TESTING AND INSTRUMENTS

Calculated effects of body shape on the bow-shock overpressures in the far field of bodies in supersonic flow. D. L. Lansing. N.A.S.A. T.R. R-76. 1960.
A theory for the supersonic flow about bodies in uniform flight in a homogeneous medium is reviewed and an integral which expresses the effect of a body shape upon the flow parameters in the far field is reduced to a form which may be readily evaluated for arbitrary body shapes. This is then used to investigate the effect of nose angle, fineness ratio, and location of maximum body cross section upon the far-field pressure jump across the bow shock of slender bodies. Curves are presented showing the variation of the shock strength with each of these parameters.—(1.2.3.2).

Analytic study of induced pressure on long bodies of revolution with varying nose bluntness at hypersonic speeds. V. Van Hise. N.A.S.A. T.R. R-78. 1960.
Pressure distributions and shock shapes for a series of cylindrical afterbodies having nose fineness ratios from 0·4 to 4 have been calculated by using the methods of characteristics for a perfect gas. The fluid mediums investigated were air and helium; Mach numbers were from 5 to 10.—(1.2.3.2×1.6.1).

A technique for determining relaxation times by free-flight tests of low-fineness-ratio cones; with experimental results for air at equilibrium temperatures up to 3440°*K. J. D. Stephenson. N.A.S.A. T.N. D*-327. *Sept.* 1960.
Relaxation times were determined by measuring the shapes of the bow shock waves on low-fineness-ratio cones in free flight and comparing these wave shapes with those calculated by a theory applicable to non-equilibrium flow.—(1.2.3.2×32.2.2×25.2×32).

Some examples of the applications of the transonic and supersonic area rules to the prediction of wave drag. R. L. Nelson and C. J. Welsh. N.A.S.A. T.N. D-446. *Sept.* 1960.
The experimental wave drags of bodies and wing-body combinations over a wide range of Mach numbers are compared with computed drags of the supersonic area rule and with the results of equivalent-body tests. A rapid method of computing wing area distributions and area-distribution slopes is given.—(1.2.2.1×1.2.3.1).

Flow Properties of an Unyawed 10*-Deg Cone for* $\gamma=1{\cdot}28$ *to* 1·40 *at Mach Numbers of* 1·5 *to* 8. *W. T. Strike, Jr. and B. B. Norton, Jr. A.E.D.C.-T.N.*-60-178. *Oct.* 1960.
Numerical solutions for a nonlinear differential equation proposed by G. I. Taylor and J. W. Maccoll to describe the flow about a cone were carried out on an I.B.M. 704 high speed computer for variable ratios of specific heats. The solutions were obtained for an unyawed 10° semi-angle cone at $\gamma=1{\cdot}40$, 1·36, 1·32 and 1·28 at Mach numbers 1·5 to 8·24.–(1.2.3.1×22.1).

CONTROLS *see also* STABILITY AND CONTROL
WINGS AND AEROFOILS
AEROELASTICITY
MISSILES
PROPELLERS

An experimental investigation of the deflection of a free-air jet by a flapped wing: the superadditive effects of shielded flow control devices. D. J. Marsden and P. J. Pocock. N.R.C. Report L.R.-285. *July* 1960.
Methods for improving the slipstream deflection effectiveness of a 40 per cent chord single-slotted double flap were studied experimentally using a half-wing model in a free-air jet. The tests were conducted out of ground effect.—(1.3.3×29.9).

A review of the jet flap. G. K. Korbacher and K. Sridhar. U.T.I.A. Review 14. *May* 1960.
A review is presented of the theoretical and experimental advances that have been made in the study of pure jet flaps, jet control and jet-augmented flaps. Care was taken in defining acting forces and in presenting all equations and graphs in a unified notation. Theories are correlated. Experimental results are quoted, illustrated by relevant graphs and compared with theory. Jet mixing and the jet flap's implication on aircraft design are included. An attempt is made to assess the jet flap on the basis of its possible merits and de-merits. Future research projects are listed.—(1.3.4×1.10.1.2).

FLUID DYNAMICS *see also* SCIENCE GENERAL

An experimental study of the ionization of low-density gas flows by induced discharges. R. L. Barger et al. *N.A.S.A. T.N. D*-431. *Sept.* 1960.
A 40-megacycle oscillator was used to produce and maintain induced discharges in argon and mercury-vapour flows. Methods for preventing blowout of the discharge were determined, and power measurements were made with an in-line wattmeter. Some results with damped oscillations pulsed at 1,000 pulses per second are also presented.—(1.4.4×32.1×32.2×27.7).

Calculation of potential flow about bodies of revolution having axes perpendicular to the free stream direction. J. L. Hess. Douglas Report E.S. 29812. *Oct.* 1960.
A general method of solving the title problem for arbitrary bodies is described. The method is derived, discussed, and its calculations compared with analytic results and experimental data.—(1.4.1).

INTERNAL FLOW *see also* TESTING AND INSTRUMENTS
AIRCRAFT OPERATION
POWER PLANTS

Further tests of cast C4 blades in the vortex wind tunnel. D. J. Close. A.R.L. Note M.E. 239. *June* 1960.—(1.5.2.1).

LOADS *see also* COMPRESSIBLE FLOW
STABILITY AND CONTROL
MISSILES

*Flow in the base region of axisymmetric and two-dimensional configurations. M. A. Beheim. N.A.S.A. T.R. R-*77. 1960.
An investigation has been conducted of the pressure distribution on the surface of either a circular cylinder or a truncated cone located within the base region of another circular cylinder at Mach number 2. A similar analysis of pressure distribution was made for rearward-facing two-dimensional steps, and theoretical results were compared with experimental results of earlier investigations. Effects of base bleed were also studied with the axisymmetric configurations.—(1.6.1×1.2.3.2).

PERFORMANCE *see* STABILITY AND CONTROL
POWER PLANTS

STABILITY AND CONTROL

*Aerodynamic characteristics of a large-scale unswept wing-body-tail configuration with blowing applied over the flap and wing leading edge. H. C. McLemore and J. P. Peterson. N.A.S.A. T.N. D-*407. *Sept.* 1960.
Tests were conducted in the Langley full-scale tunnel to determine the effects of blowing boundary layer control on the aerodynamic characteristics of a large-scale, wing-body-tail configuration having an unswept wing with an aspect ratio of 2·86 and a thickness ratio of 0·04. The tests were conducted for a range of angles of attack from approximately −4° to 23° for a Reynolds number of approximately $5{\cdot}2\times10^6$ corresponding to a Mach number of 0·08. Longitudinal stability and control characteristics were obtained for three tail heights, and lateral-control characteristics for two aileron and several spoiler configurations.—(1.8.2.2×1.1.6.1×1.3.4×1.3.8×1.7×1.6.1).

Low-speed measurements of static and oscillatory lateral stability derivatives of a 1/5*-scale model of a jet-powered vertical-attitude V.T.O.L. research airplane. R. E. Shanks and C. C. Smith. N.A.S.A. T.N. D-*433. *Sept.* 1960.
Force tests of the static and dynamic lateral stability characteristics of a V.T.O.L. aeroplane having a triangular wing mounted high on the fuselage with a triangular vertical tail on top of the wing and no horizontal tail, have been made in the Langley free-flight tunnel. The static lateral stability parameters and the rolling, yawing, and sideslipping dynamic stability derivatives are presented without analysis.—(1.8.1.2×3.12).

Investigation of the static longitudinal stability characteristics of a 0·067*-scale model of a four-stage configuration of the Scout research vehicle at Mach numbers of* 2·29, 2·96, 3·96, *and* 4·65. *L. S. Jernell and N. Wong. N.A.S.A. T.N. D-*554. *Sept.* 1960.
An investigation was made to determine the effect of fin area and second-stage flare angle on the static longitudinal stability of a 0·067-scale model of a four-stage Scout vehicle. The tests were performed at Reynolds numbers of about $4{\cdot}6\times10^6$ per foot. The effect of Reynolds number was investigated.—(1.8.2.2×25.2).

Force tests of an AGARD calibration model B at $M=2{\cdot}5$ *to* 6·0. *J. D. Coats. A.E.D.C.-T.N.-*60-182. *Oct.* 1960.
An AGARD Calibration Model B body-wing configuration was tested in the 40 in. supersonic wind tunnel (Tunnel A) of the von Kármán Gas Dynamics Facility. Force and moment coefficients were determined over a range of pitch and yaw angles from −4 to +10 degrees at Mach numbers from 2·5 to 6·0. Reynolds numbers were 2×10^6 to 24×10^6 based on body length.—(1.8.0.2×1.1.2.4).

THERMO-AERODYNAMICS *see also* BOUNDARY LAYER
EXTRA-ATMOSPHERIC
TECHNOLOGY

*Effect on gaseous film cooling of coolant injection through angled slots and normal holes. S. S. Papell. N.A.S.A. T.N. D-*299. *Sept.* 1960.—(1.9.1×34.3.4).

*Heat addition to a one-dimensional supersonic flow including real gas effects. S. A. Waiter. A.E.D.C.-T.N.-*60-180. *Sept.* 1960.
The thermodynamic study of heat addition process in a supersonic flow is presented, taking account of the effects of dissociation and ionisation; the only hypothesis proposed is that the flow is in thermodynamic equilibrium at each point. The specific mechanism of the heat source is not given in detail, but, it will be supposed that the heat added to the system is steady and constant per unit distance along the nozzle axis.—(1.9.3×34.1×1.2.3.1).

WINGS AND AEROFOILS *see also* BOUNDARY LAYER
CONTROLS
PROPELLERS

Measurements of the velocity at the vortex centre on an A.R.1 delta wing by means of smoke observations. A. P. Cox. C.P. 511. 1960.—(1.10.2.2).

The calculation of lift slopes, allowing for boundary layer, with applications to the R.A.E. 101 *and* 104 *aerofoils. D. A. Spence and J. A. Beasley. R. & M.* 3137. 1960.—(1.10.1.2×1.1.2.1).

A note on the total drag of jet flapped wings. G. K. Korbacher and K. Sridhar. U.T.I.A. Report 64. *May* 1960.
The limitations of the drag hypothesis for jet-flapped wings are discussed from the theoretical and experimental point of view. An empirical relation for calculating the total drag coefficient of quasi two-dimensional jet-flapped wings at zero incidence is derived and presented. This drag coefficient relation, combined with the expression for the total lift coefficient provides an expression for the slope of the C_{DT}/C_{LT} curve. The slopes obtained are in qualitive agreement with those given by Maskell and Spence's theory.—(1.10.1.2×1.3.4).

HELICOPTER AERODYNAMICS *see also* FLIGHT TESTING

*Effects of control-response characteristics on the capability of a helicopter for use as a gun platform. R. J. Pegg and A. B. Connor. N.A.S.A. T.N. D-*464. *Sept.* 1960.—(1.11.2×3.9).

TESTING AND INSTRUMENTS *see also* ELECTRONICS

*A miniature wafer-style pressure transducer. W. E. Smotherman. A.E.D.C. T.R.-*60-11. *Oct.* 1960.
The wafer gauge provides a series of pressure ranges from 0-0·5 to 0-5·0 lb./in.² by means of interchangeable diaphragms. Although 0-0·5 lb./in.² is the lowest range specified for the wafer gauge, it is frequently calibrated for full scale output at 0·01, and pressure differentials of 30 microns of mercury can be resolved. Because of the convenient wafer shape and the miniature size of this transducer, it may be used in many applications where larger transducers are not feasible.—(1.12.6.1).

Performance of a 40*-mm combustion-heated light gas gun launcher. M. E. Lord. A.E.D.C.-T.N.-*60-176. *Oct.* 1960.—(1.12.1.3×1.2.3).

*A prototype high speed digital system for hotshot tunnels. G. E. Gilley and M. L. Bunn. A.E.D.C.-T.N.-*60-177. *Oct.* 1960.
A prototype high speed digital system has been built and tested in two of the arc-discharge wind tunnels at the von Kármán Gas Dynamics Facility, A.E.D.C. The system is used in conjunction with a carrier-amplifier and recording oscillograph system to obtain digital data in parallel with the analogue data. Numerical transformation of the analogue signals is accomplished by using a high speed electronic commutator to switch the signals into an analogue-to-digital converter. The data are stored at high speed in a magnetic core storage and later transferred to paper tape. The purpose of the digital system is to obtain a large amount of raw data in a form compatible for reduction with digital computers.—(1.12.6×1.12.1.3×18.1).

An investigation of the boundary-layer characteristics in the test section of a 40 *by* 40*-inch supersonic tunnel. J. Jones. A.E.D.C.-T.N.-*60-189. *Oct.* 1960.
A test programme was conducted to investigate the boundary layer characteristics of the von Kármán Gas Dynamics Facility's 40 by 40 in., continuous, supersonic wind tunnel. The programme was divided into two parts: (1) A survey of the boundary layer at one station at the centre of the flexible nozzle plate (curved wall) and (2) a survey at one station at the centre of the tunnel sidewall. Results of the investigation

at Mach numbers from 1·5 to 5·5 in half Mach number increments are presented in the form of boundary layer total thickness, displacement thickness, and momentum thickness over a Reynolds number range of $1{\cdot}0\times10^6$ to $6{\cdot}5\times10^6$ per foot.—(1.12.1.3×1.5.1.4×1.1.0.4).

Aerodynamic sound and pressure fluctuations in a supersonic blowdown wind tunnel. R. Westley. N.R.C. Report L.R.-274. *Jan.* 1960.—(1.12.1.3×1.5.1.4).

AEROELASTICITY

Flexible mass-balance arms and control-surface flutter. D. Moxon. R. & M. 3167. 1960.—(2×1.3.1).

AIRCRAFT

See also AERODYNAMICS—STABILITY AND CONTROL
HELICOPTER AERODYNAMICS
STRUCTURES—THEORY AND ANALYSIS

Thrust characteristics of multiple lifting jets in ground proximity. E. E. Davenport and K. P. Spreemann. N.A.S.A. T.N. D-513. *Sept.* 1960.
An investigation of a series of nozzle lifting-surface combinations which might represent a V.T.O.L. configuration which used direct thrust from wing- or fuselage-mounted engines for take-off has been made. Configurations tested include a simple jet, 4, 6 and 8 exit multiple jets and a double jet with fuselage.—(3.12×27.1).

Pressure distribution and force measurements on a V.T.O.L. tilting wing-propeller model. Part II. Analysis of results. M. M. Currie and J. A. Dunsby. N.R.C. Report L.R.-284. *June* 1960.
Results presented in Report LR-252 from pressure distribution and force measurements on a half-wing model of a twin-engined tilt-wing V.T.O.L. configuration are presented in graphical form. The profound influence of the slipstream on these results is discussed.—(3.12×29.9).

AIRCRAFT OPERATION

See also FLIGHT TESTING
SCIENCE—GENERAL

Experimental and theoretical studies of axisymmetrical free jets. E. S. Love et al. *N.A.S.A. T.R. R*-6. 1959.
Results are presented of some experimental and theoretical studies made of axisymmetric jets exhausting from sonic and supersonic nozzles into still air and into supersonic streams with a view toward problems associated with propulsive jets and the investigation of these problems.—(5.6×27×1.5.1).

The "Tee" visual glidepath (T.V.G.): an alternative type of visual approach aid. J. R. Baxter and J. C. Lane. A.R.L. Note H.E. 7. *July* 1960.
Discussions on the relative merits of the Australian P.V.G. and the British V.G.P.I. have revealed certain disadvantages in both systems. Another system designed to give precise visual glidepath guidance without any of the known disadvantages of these two well-tested systems is described. Although preliminary tests of a rough mock-up have revealed problems of a different type, further tests will be made with better equipment.—(5.3×9).

EXTRA-ATMOSPHERIC TECHNOLOGY

See also POWER PLANTS

The effect of lift on entry corridor depth and guidance requirements for the return lunar flight. T. J. Wong and R. E. Slye. N.A.S.A. T.R. R-80. 1960.—(8.2×1.9.1×26).

Determination of azimuth angle at burnout for placing a satellite over a selected earth position. T. H. Skopinski and K. G. Johnson. N.A.S.A. T.N. D-233. *Sept.* 1960.
Orbit characteristics and expressions are presented for relating the satellite position in the orbital plane with the projected latitude and longitude on a rotating earth surface. An expression is also presented for determining the azimuth angle at a given burnout position on the basis of a selected passage position on the earth's surface. Two examples are compared with results for an oblate rotating earth.—(8.2×25.1×25.2).

Interim definitive orbit for the satellite 1958-*Epsilon, Explorer IV. Goddard Space Flight Center. N.A.S.A. T.N. D*-410. *Sept.* 1960. *Interim definitive orbit for the satellite* 1958-*Alpha, Explorer I. Goddard Space Flight Center. N.A.S.A. T.N. D*-359. *Sept.* 1960.
A summary of certain position information indicating accuracies for the orbital arcs underlying the ephemeris is presented. The detailed ephemeris information is presented in the form of tables which give the latitude and longitude of the subsatellite point and the satellite height for each minute of time. The subsatellite point is defined as the point on the earth's surface over which the satellite was determined to be at the indicated time. This form of presentation was recommended by the I.G.Y. agencies concerned, for use in specifying the orbital positions of I.G.Y. satellites. Time is specified by giving in columns, the day, hour, and minute of Greenwich mean time. Longitude and geographic latitude are specified to the nearest second of arc. East longitudes and north latitudes are taken as positive. The satellite height is expressed in kilometers to four decimal places.—(8.2).

Project Vanguard magnetic-field instrumentation and measurements. J. P. Heppner et al. *N.A.S.A. T.N. D*-486. *Sept.* 1960.
The Vanguard III satellite, 1959 Eta, contained a proton precessional magnetometer for magnetic-field studies of exceptional accuracy. The instrumentation used in the experiments, and the data collection and reduction procedures, are reviewed. Emphasis is given to results from a preliminary analysis. This analysis bears on the accuracy of computed fields, the stability of the earth's field in space, the Capetown anomaly, and the magnetic-storm effects.—(8.2×32.2.1).

Recent direct measurements by satellites of cosmic dust in the vicinity of the earth. H. E. LaGow and W. M. Alexander. N.A.S.A. T.N. D-488. *Sept.* 1960.
Direct measurements of the space density of cosmic dust particles in the vicinity of the earth have been made from rockets, satellites, and space probes. The largest data samples have been obtained from crystal transducer sensors that detect the impact impulses occurring from the collision of dust particles on sensitive surfaces of space vehicles.—(8.2).

Determination of satellite orbits from radar data. W. F. Cahill and I. Harris. N.A.S.A. T.N. D-489. *Sept.* 1960.
An optimum method for determining satellite orbits from radar data is presented, which makes use of orbit inclination and orbit elements in the plane, and proceeds with a differential correction of the orbit elements.—(8.2).

Ionospheric measurements using environmental sampling techniques. R. E. Bourdeau et al. *N.A.S.A. T.N. D*-491. *Sept.* 1960.
Two rockets were flown to peak altitudes of 220 km to test various methods planned for future measurements of ionisation parameters in the ionosphere, exosphere, and interplanetary plasma. Techniques were used which sample the ambient environment in the immediate vicinity of the research vehicle.—(8.1).

The limiting sizes of the habitable planets. S-S Huang. N.A.S.A. T.N. D-499. *Sept.* 1960.
The astrobiological problem of the occurrence of life in the universe is discussed from the standpoint of the size and nature of planets upon which living organisms might arise. Conditions of temperature and density also bear upon the occurrence of life.—(8.1).

Very restricted four-body problem. S-S Huang. N.A.S.A. T.N. D-501. *Sept.* 1960.
A state of motion of three finite bodies is idealised by an approximation to the law of mechanics such that m_2 and m_3 revolve around each other in circular orbits and that their centre of mass revolves around m_1, also in a circular orbit. The motion of a fourth body of an infinitesimal mass is then studied in a similar manner.—(8.2×32.2×22.2).

Some dynamical properties of the natural and artificial satellites. S-S Huang. N.A.S.A. T.N. D-502. *Sept.* 1960.
Some qualitative properties of the natural and artificial satellites in the solar system that can be understood in terms of the restricted three-body problem are discussed. Three problems are considered: The satellite system of Jupiter, the Trojan group of asteroids, and the behaviour of artificial satellites in the Earth-Moon-Sun system.—(8.1×8.2×32.2).

AVIATION MEDICINE

See AIRCRAFT OPERATION

ELECTRONICS

The design and evaluation of a transistorized current amplifier with a bandwidth of D.C. to 100 *K.C. W. M. Crouch. A.E.D.C.-T.N.*-60-194. *Oct.* 1960.—(11×1.12.6×18.1).

FLIGHT TESTING

Description of the spray rig used to study icing on helicopters in flight. 2nd revised edition. D. L. Bailey. N.R.C. Report L.R.-186*A. Sept.* 1960.—(13×5.3×1.11×24).

INSTRUMENTS AND EQUIPMENT

See AERODYNAMICS—TESTING AND INSTRUMENTS
ELECTRONICS

MATERIALS

See STRUCTURES—THEORY AND ANALYSIS

MATHEMATICS

See also AERODYNAMICS—COMPRESSIBLE FLOW
EXTRA-ATMOSPHERIC TECHNOLOGY

Some characteristics of two simple linear and stochastically time-varying control systems of interest in angle and range measurement and tracking by monopulse radar. G. Hellgren. S.A.A.B. T.N. 47. *May* 1960.—(22.1).

METEOROLOGY

See also FLIGHT TESTING

Notes on the derivation of true air temperature from aircraft observations. D. D. Clark. R. & M. 3126. 1960.—(24).

MISSILES

See also AERODYNAMICS—COMPRESSIBLE FLOW
STABILITY AND CONTROL
EXTRA-ATMOSPHERIC TECHNOLOGY

Effects of Reynolds number on the force and pressure distribution characteristics of a two-dimensional lifting circular cylinder. V. E. Lockwood and L. W. McKinney. N.A.S.A. T.N. D-455. *Sept* 1960.
Pressure distribution and force data were obtained on a cylinder having small flaps attached to the bottom surface for the generation of lift. These tests with flaps at the 50 per cent streamwise station covered a Mach number range from 0·011 to 0·32 and a Reynolds number range from 135,000 to 1,580,000. Two flap sizes and various locations were tested. Data were obtained with flaps 180° apart.—(25.2×1.3.4×1.6.1).

NAVIGATION

See EXTRA-ATMOSPHERIC TECHNOLOGY

POWER PLANTS

See also AERODYNAMICS—FLUID DYNAMICS
AIRCRAFT
AIRCRAFT OPERATION
THERMODYNAMICS

Fast interplanetary missions with low-thrust propulsion systems. W. E. Moeckel. N.A.S.A. T.R. R-79. 1960.
A simple family of indirect transfer trajectories between circular orbits is used to evaluate the mass ratio required to complete round-trip interplanetary missions using low-thrust propulsion systems.—(27×8.2×1.7).

Performance of several conical convergent-divergent rocket-type exhaust nozzles. C. E. Campbell and J. M. Farley. N.A.S.A. T.N. D-467. *Sept.* 1960.
Nozzles with divergence angles of 15°, 25° and 29° were each tested at area ratios of approximately 10, 25 and 40 at pressure ratios up to 120. Heated air (1200°F) was supplied at the nozzle inlet at pressures up to 145 lb./in.² abs. and was exhausted into quiescent air at pressures as low as 1·2 lb./in.² abs. A simplified method of thrust determination was developed for conical nozzles that permitted the calculation of thrust in the separated-flow region from unseparated static-pressure distributions.—(27.3.1×1.5.1).

The effect of catalyst-bed arrangement on thrust buildup and decay time for a 90 *percent hydrogen peroxide control rocket. C. M. Willis. N.A.S.A. T.N. D*-516. *Sept.* 1960.
Chamber-pressure-buildup and decay lag times have been measured for a 35 lb. thrust control rocket. Five arrangements of a catalyst bed and decomposition chamber were investigated. The test quantities measured were chamber pressure and rocket-case temperature.—(27.3.1).

PROPELLERS

See also AERODYNAMICS—CONTROLS
AIRCRAFT

The static and forward speed testing of a flapped wing with boundary layer control for use in deflecting propeller slipstreams downward for vertical take-off. Part 1. *B. Neal. N.R.C. Report L.R.*-288. *July* 1960.
Force and moment data are presented for a four-propeller model of a slipstream deflection type V.T.O.L. aircraft wing using a slotted forward flap together with a plain rear flap over which boundary layer control air was blown. Tests were performed out of ground effect both statically and at forward speed for a wide range of flap settings on a mobile test rig that can be towed at speeds up to 50 ft./sec.—(29.9×1.10.2.2×1.1.6.1×1.3.4).

SCIENCE—GENERAL

See also AERODYNAMICS—COMPRESSIBLE FLOW
FLUID DYNAMICS
EXTRA-ATMOSPHERIC TECHNOLOGY
THERMODYNAMICS

Diffusion of sound waves in a turbulent atmosphere. R. H. Lyon. N.A.S.A. T.N. D-456. *Sept.* 1960.
The directional and frequency diffusion of a plane monochromatic sound wave in statistically homogeneous, isotropic, and stationary turbulence is analysed theoretically. A form for frequency-wave number spectrum of turbulence is adopted which contains the pertinent parameters of flow. A new approach to the evaluation of the characteristic period of flow is suggested. The spectrum is then related to the scattering cross section. A diffusion equation is derived as a small-angle scattering approximation to the rigorous transport equation. The rate of spread of the incident wave in frequency and direction is calculated as well as the power spectrum and autocorrelation for the wave.—(32.2.3×5.6×1.4.2).

Recherches sur les propriétés optiques des carbures aromatiques. A. Téryan. Pubs. Sc. et Techs. N.T. 91. 1960.—(32.2.4).

Étude des spins et parités de niveaux excités de noyaux par des méthodes d'orientation aux basses températures, de corrélations angulaires et de corrélations direction-polarisation. J-P Perez y Jorba. Pubs. Sc. et Techs. N.T. 92. 1960—(32.2.5).

STRUCTURES

THEORY AND ANALYSIS

Structural considerations of inflatable reentry vehicles. R. W. Leonard et al. *N.A.S.A. T.N. D*-457. *Sept.* 1960.
The state of the design art for inflated structures applicable to re-entry vehicles is discussed. Included are material properties, calculations of buckling and collapse loads, and calculations of deflections and vibration frequencies. A new theory for the analysis of inflated plates is presented.—(33.2.3.0×21×3.3).

THERMODYNAMICS

See also AERODYNAMICS—THERMO-AERODYNAMICS

Propagation of free flames in laminar- and turbulent-flow fields. R. E. Bolz and H. Burlage. N.A.S.A. T.N. D-551. *Sept.* 1960.
The results of study of the influence of screen-induced turbulence on flame-propagation velocity are presented. A refinement of the previously reported flame-kernel growth experimental technique was used. The data indicate flame speeds in flowing mixtures of air and natural gas which agree with measurements using other techniques. An improved method of turbulence-free spark ignition is described.—(34.1.2×27.3).

The equation of state of an ionized gas. D. P. Duclos. A.E.D.C.-T.N.-60-192. *October* 1960.—(34.1×32.2.2).